Thesis
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Reports
Wyoming

Interim Progress Report
December, 1972

THE MEDICINE BOW ECOLOGY PROJECT

Prepared for the

Office of Atmospheric Water Resources
U.S. Bureau of Reclamation
Department of the Interior
Denver, Colorado 80225

by

The University of Wyoming
Laramie, Wyoming 82070

in cooperation with

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Contract No. 14-06-D-7198

THESIS
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THE MEDICINE BOW ECOLOGY PROJECT

An Evaluation of the Sensitivity of Various Ecosystem Components to Winter Precipitation Management in The Medicine Bow Mountains, Wyoming

Interim Progress Report
for the period
September 1971 - December 1972

Contract No. 14-06-D-7198

Co-Principal Investigators

Dennis H. Knight, Coordinator, Plant Ecology
A. Duane Anderson, Toxicology
George Baxter, Fish Ecology
Kenneth Diem, Big Game Ecology
Michael Parker, Limnology
Paul Singleton, Soils
John Thilenius, U.S.F.S., Plant Ecology
A. Lorin Ward, U.S.F.S., Big Game Ecology
Paul Rechard, W.R.R.I., Hydrology
Richard Weeks, Engineering, Radio Telemetry

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ACKNOWLEDGMENTS

Numerous individuals have contributed to the initiation of the Medicine Bow Ecology Project, but none have played a more vital role than our research assistants, both full-time and part-time. Their names and projects are as follows:

Silver monitoring and toxicity

Roger Hunter
James Lemley
Herbert McCoy
Randall White

Elk ecology

Jerry Cupal
Al Lea
Dale Strickland

Aquatic research

Steve Condit
Ray Czaplewski
Jim Loar
Tim Paschke

Vegetation research

Gary Brown
Ned Fetcher
Ron Geedman
John Keck
Clay Kyte
Brant Rogers
Richard Starr

Special acknowledgment is also in order for Dr. Wilhelm Solheim for identification of two plant-parasitic fungi; Mr. Irwin Patterson for a set of his data on lodgepole pine forest phytosociology; Dr. Jack Ives for allowing Mr. Patterson to work with our group last summer; Mr. Carl James of the Bureau of Reclamation for his assistance with a variety of problems; Marie Ballas, Shirley Shurtleff, Linda Boone and Vera Collins

for special secretarial assistance; and our colleagues working on the San Juan Ecology Project who have shared ideas and results with us.

The Water Resources Research Institute (WRRI) at the University of Wyoming, directed by Professor Paul Rechard, has contributed to the progress reported herein, both by assisting with instrument installation and by fiscal administration. Field work was facilitated greatly by the University of Wyoming Science Camp which is conveniently located near most of the study areas.

INTRODUCTION AND OBJECTIVES

Regardless of the specific resource being managed, the management techniques always lead to secondary ecological changes. This occurs because of the many interactions that are characteristic of the ecosystems in which man operates. The ecological changes that occur may not be detrimental, but often they are and any modern management program should have sufficient ecological information so that unfortunate consequences can be avoided.

Precipitation management is a rather new way of modifying ecosystems, and consequently little is known about the potential secondary changes that may occur where rainfall or snowfall is increased over a period of years. With this in mind, and in anticipation of a winter cloud seeding program for the Medicine Bow Mountains of Wyoming, an interdisciplinary research program was initiated to 1) predict probable secondary effects of the planned winter cloud seeding program, and 2) evaluate the ecological impact of cloud seeding when it actually occurs. The basic question for the Medicine Bow Project is, "How will the ecosystem change if the mean annual snowfall is increased by cloud seeding with silver iodide?" Since it has been impossible to develop a research program to study the entire ecosystem, the research is focused on the sensitivity to increased snowfall of certain key components and processes in the ecosystems of the Medicine Bow Mountains. Seven separate studies can be identified:

1. The impact of snow on herbaceous and shrubby vegetation.
2. The impact of snow on big game, especially elk.
3. The impact of spring run-off on trout and their food.
4. The impact of spring run-off on mountain lake productivity.
5. The impact of snow on litter decomposition and nutrient leaching.
6. The sensitivity of trout to various silver salts.
7. The movement of silver in ecosystems.

The necessity of studying other ecosystem components and processes will be determined as the research progresses. The investigators are fully cognizant of the value of a systems analysis approach to their research, and this will be done wherever possible.

The Medicine Bow Mountains provide a variety of ecosystems in which to evaluate the ecological effects of winter precipitation management, and considerable information is already available on certain characteristics of this area. Predicting the effect of cloud seeding, however, requires some very specific information that is just now becoming available. Cooper and Jolly (1969) write,

> "Ecological effects of weather modification will be the result of moderate shifts in rates of reproduction, growth, and mortality of weather sensitive species of plants and animals."

It is not yet known which species are the most weather sensitive in the Medicine Bow Mountains, nor is it possible to speak confidently about the effects of weather modification on reproduction, growth, and mortality. Our research will provide information of this kind.

Cloud seeding has not begun yet on the Medicine Bow Mountains, and even if it had one year of study would be inadequate, in most cases, for evaluating ecological impact. This Interim Report, therefore, does not provide a basis for conclusions. Considerable information about the

Medicine Bow ecosystems has been acquired during the first year, however, and this is summarized along with the methods that were used for each specific study.

GENERAL OVERVIEW

The contract between the Bureau of Reclamation and the University of Wyoming was established in September, 1971, and shortly thereafter a Cooperative Agreement (No. 16-252-CA) was established between the University and the Rocky Mountain Forest and Range Experiment Station (U. S. Forest Service). The Forest Service scientists (Thilenius and Ward) have worked closely with University scientists in developing the research program. Numerous meetings were held during the winter (1971-72) in order to select study areas and evaluate research design. Considerable effort was devoted during this time to the synthesis of existing knowledge about the ecosystems of the Medicine Bow Mountains.

Snow persists until late June in much of the Medicine Bow Mountains, but field work began as soon as possible. Specific study areas were selected and a variety of instruments were installed for meteorological data. Data from elk "marked" with radio transmitters were already being collected in January, 1972, and the first results on silver toxicity to Brook Trout were available in July. For most of the seven specific studies, the summer was spent setting up experiments, calibrating instruments, testing methodology, gathering data on species composition, and collecting samples for analysis during the winter. Not all samples nor all of the data have been analyzed, but an attempt has been made to make this report as complete as possible.

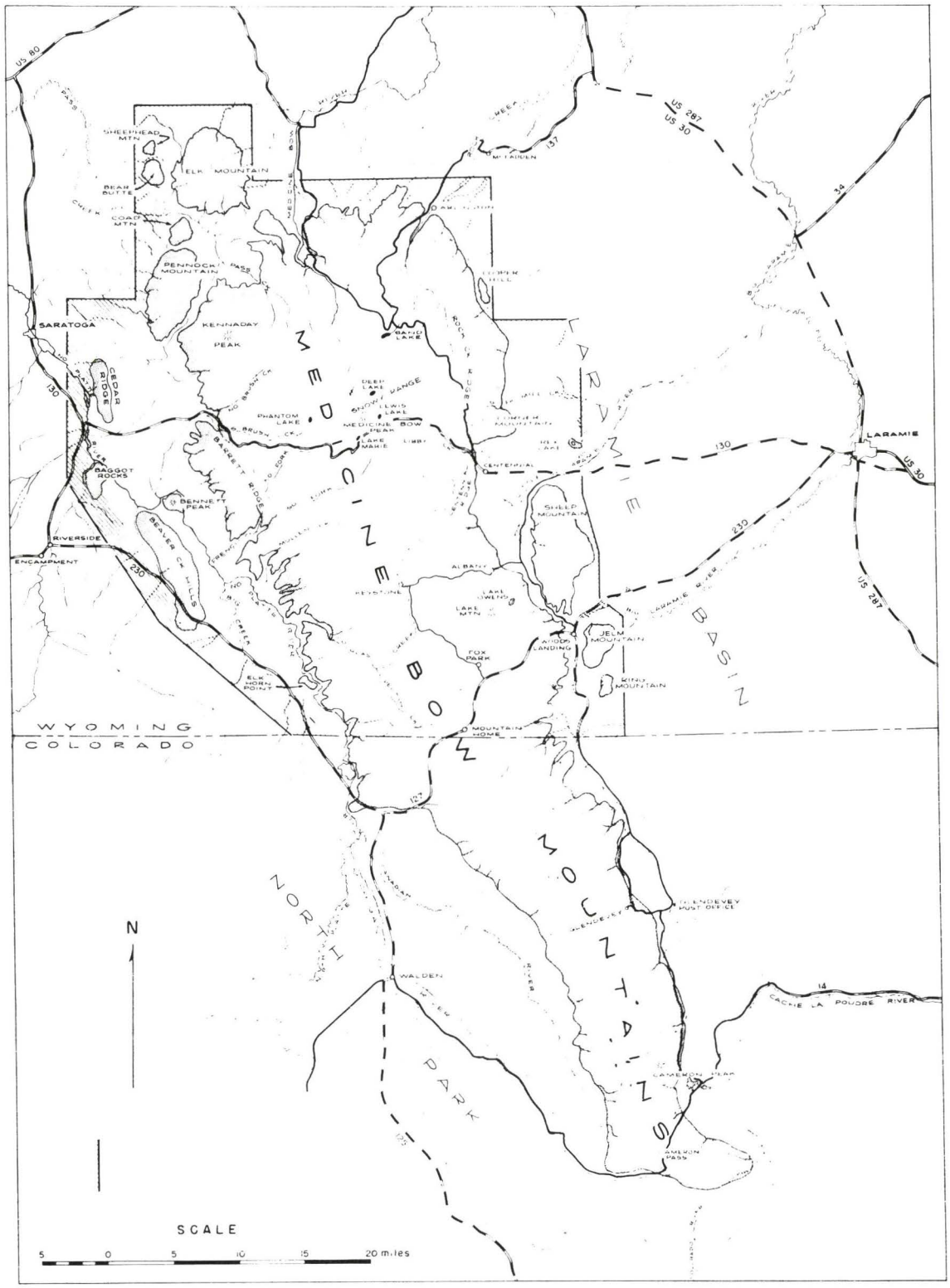

Figure 1. Index map of The Medicine Bow Mountains (from Houston et al. 1968).

THE MEDICINE BOW MOUNTAINS

The Medicine Bow Mountains* are located in southeastern Wyoming, 30 miles west of Laramie, and are composed primarily of a complex uplifted mass of Precambrian rocks (Houston, et al., 1968). Sedimentary rocks of Paleozoic, Mesozoic, and Tertiary age are found in the center of the range as well as on the flanks. Pleistocene glacial deposits are abundant in the north, having originated from an ice cap near Medicine Bow Peak (12,013 ft. elevation). Surrounded by plains that are about 6,000 to 7,000 feet in elevation, the mountains rise rather abruptly to a rolling plateau at about 10,500 feet. Libby Flats comprises much of this plateau which is broken by the Snowy Range, a six-mile long axial remnant in the north-central portion of the mountains.

The mountains receive a large amount of snow during the winter, though the amount may vary up to 100 percent from one year to the next. Snowmelt water is very important to the mountain ecosystems and to the maintenance of streamflow in 8 principle watersheds, all of which contribute water to the Laramie River - North Platte River drainage system (Figure 1). Over 80 percent of the runoff occurs between April and July, with most of the streams having 2 or 3 peaks in flow rate (Allen & Smith, 1972), due to different melt patterns of lower and upper snow. Frequent high winds cause considerable drifting of the snow and drift patterns are often reflected by the vegetation. The climatic and hydrologic characteristics of the mountains are summarized by Rechard & Smith (1972). Since cloud seeding would probably be effective only

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*The Medicine Bow Mountains extend south into Colorado, but this report is limited to the Wyoming portion.

above about 9,000 feet, the usual bottom of the orographic clouds on the western slopes, it is of interest to note that about 49 percent of the range is above 9,000 feet elevation (approximately 420 square miles).

Water yield has been estimated by the U. S. Forest Service as follows:

	Average Acre Feet/Year	Average Acre Feet/Acre/Year
Lower Laramie River	21,299	0.3128
Little Laramie River	175,634	1.8626
Rock Creek	163,733	1.9149
Douglas Creek	55,166	1.0581
French Creek	98,766	1.5964
Brush Creek	81,599	1.1733
Pass Creek	22,133	0.8421
Other	35,867	
TOTAL YIELD	654,197	

Generally, the watersheds with a higher average elevation have the highest water yield (acre feet per acre per year), probably a result of greater amounts of snow.

Human utilization of the mountains is extensive. Being almost entirely in the Medicine Bow National Forest, the land is subject to multiple use which includes recreation, grazing of sheep and cattle, lumbering, wildlife, and water. Roads penetrate most of the area, permitting easy access for most uses. Skiing and snowmobiling are very popular during the winter; and Douglas Creek, French Creek, and the North Platte River are considered to be among the best trout streams in the state, if not the nation. At the present time there is considerable debate over how the Medicine Bow National Forests should be used, whether to emphasize lumber, recreation, or water. Any cloud-seeding program is likely to meet with considerable discussion by the many people with special interests in the area. Multiple use requires compromises that are becoming

more and more difficult with greater resource demands from more and more people.

With regard to human and wildlife utilization of the area, the U. S. Forest Service released the following statistics for the Medicine Bow National Forest:

GRAZING (1971)	
Number of cattle and horse grazing allotments	17
Number of sheep and goat allotments	15
Number of cattle and horse animal-unit months	11,308
Number of sheep and goat animal-unit months	23,276
Number of cattle permitted	3,439
Number of sheep permitted	14,057
TOTAL VISITOR DAY USE (1970)*	375,000
VISITOR DAY USE BY HUNTERS AND FISHERMEN	41,000
WILDLIFE (1971)	
Antelope	93
Mule Deer	10,350
Elk	2,281
Bighorn Sheep	5
Black Bear	132
Turkey	20
CLEAR-CUT ACRES FOR LUMBER*	
FY 1969	2,584
FY 1970	1,778
FY 1971	2,318
PARTIAL-CUT ACRES FOR LUMBER*	
FY 1969	699
FY 1970	608
FY 1971	381

With regard to domestic animals, sheep grazing would be of greatest concern in the context of a winter precipitation management program, since they utilize the higher elevations more than cattle. Calving occurs below 9,000 feet. The sheep grazing season now is usually less than 2 months long, from mid-July to early September depending on weather and range conditions. Mule Deer and Elk are both common in the mountains and they

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*These data are available also for specific areas within the Medicine Bow National Forest, and for specific activities. Winter visitor days accounted for about 8 percent of the total in 1970.

are known to be affected by snow depth in other areas. Gaffney (1941) found that the amount of snow in which elk can winter successfully depends on several factors: 1) the composition, height, and volume of the palatable vegetation, 2) conditions of the snow (packed, crusted, or loose), 3) age and condition of the animals, and 4) topography and weather conditions. He found on the south fork of the Flathead River, Montana, that elk often nosed through 12 to 18 inches of loose snow while feeding on bunchgrass and frequently paw to obtain food in 36 inches of moderately loose snow. He concluded that, generally, 48 inches of snow represents the maximum in which the elk can range efficiently and that they will buck 12 to 18 inches more snow on the flats than on a hillside. He states that snow depths of 6 to 10 inches started mass migration out of Yellowstone Park. Our research will determine the liklihood of a beneficial or detrimental effect on elk by snowfall management in the Medicine Bow Mountains. Mule Deer may possibly be affected more by snow than elk because they stay in the mountains later and go higher. Fawning, however takes place in the foothills and 2 - 3 weeks later than elk calving. There are both migratory and resident deer herds in the area. Other wildlife include red squirrel, coyote, marten, grey fox, golden marmot, beaver, ground squirrels, several species of mice, and many species of birds.

A variety of research has been conducted in the Medicine Bow Mountains, largely by scientists from the University of Wyoming, Duke University, the Wyoming Game and Fish Department, and the U. S. Forest Service. Best known is the geology of the area, and least known are probably the soils and microorganisms. Considerable information is available on big game, trout, streamflow, climate and vegetation. The time is soon approaching when all of the ecological information could be usefully synthesized into one volume.

It is not yet possible to do this, but considerable progress will have been made toward this goal by the time of our Final Report (May, 1974). For now a brief and still incomplete summary must suffice.

With regard to lake ecology, rather little is known. There are over 80 lakes in the mountains, and some have a very rapid flushing rate. Little Brooklyn Lake, for example loses as much water in 10-72 hours as the lake can hold. This same Lake has a very low phytoplankton standing crop (ca. 220,000 μ^3 per ml) and a low productivity of about 100 mg per m^3 per day. Some of the lakes do stratify and anoxic conditions develop; others may freeze solid. Little information is available for the rooted aquatic plants.

No native trout occur in the Snowy Range portion of the Medicine Bow Mountains, though Brook Trout are very successful above 9,000 feet. Most Brook Trout are 4 years old or younger. A few experiments on lake fertilization have not resulted in increased fish growth; the fish grow larger when competition is reduced. Fish drift and invertebrate drift are both very important in the streams.

Beginning with the explorations in the early 1900's of Ramaley, Cary, Rydberg, Shantz, Clements, and Nelson, information has been accumulating on the vegetation ecology of the Medicine Bow Mountains and the Rocky Mountains in general. In 1934, Hanna published the first description of the plant communities in one section of the mountains, but even before then, in 1912, Douglas had produced a vegetation map for most of the Medicine Bow Mountains for the U. S. Forest Service. The Forest Service has since then completely re-mapped the mountains in considerable detail using aerial photographs. The S.H. Knight Science Camp was established by the University of Wyoming in 1925, and it has attracted a variety of

investigators from several universities. Dr. Dwight Billings and his students from Duke University lived at the camp while doing a large amount of alpine vegetation research on Libby Flats and Medicine Bow Peak, and R. Daubenmire collected material while at the camp for his review paper on vegetation zonation in the Rocky Mountains (1943). A student of Daubenmire's is currently finishing a thesis on vegetation classification in the Medicine Bow National Forest.

The vegetation of the mountains has probably not changed much since glaciers moved down the slopes of Medicine Bow Peak over 8,000 years ago. The pollen record is not well studied, but it seems reasonable now to assume that lodgepole pine (Pinus contorta Dougl.), aspen (Populus tremuloides Michaux), and Engelmann Spruce (Picea engelmannii, Parry) invaded the till as the glaciers retreated. Today these same tree species dominate the forest vegetation, along with subalpine fir (Abies lasiocarpa (Hook.) Nutt.) which has been in the mountains also since before Pleistocene glaciation.

Following glaciation, the most frequent disturbance for thousands of years was fire, caused both by lightning and the native American Indian. Evidence of fire is abundant, and lodgepole pine seems to almost depend on periodic fire for its existence. Billings studied old stumps on Libby Flats, and concluded that much of the Flats were forested previous to fires in 1766, 1774, and 1809. Libby Flats is now a wind-swept sub-alpine meadow (tundra) in which spruce are invading very slowly as islands of Krummholz.

Other forest fires of note occurred in 1860 and 1871. In 1860 the fires were started by the Ute Indians as they were being harassed by the U. S. Calvary, at the time the Union Pacific Railroad was building around

the north end of the mountains. In 1871 the Laramie Daily Sentinel reported that fires were so abundant that the mountains could not be seen from the city for a 2 month period. These fires undoubtedly favored the development of pioneer forests dominated by lodgepole pine and aspen, and they probably served also to keep the native mistletoe in check. Some forests did apparently go unburned, for example the spruce-fir natural area above Science Camp where Engelmann spruce have been aged at 500 years old. All of the tree species above 9,000 feet elevation are quite intolerant to any kind of fire, unlike ponderosa pine (Pinus ponderosa Laws.) at the lower elevations.

Fires are still frequent in the Medicine Bow Mountains, but every effort is made to control them immediately. It is interesting to wonder whether the control of fire has in fact changed the Medicine Bow ecosystems more than a 15 percent increase in snowfall would. Arguing against the control of fire verges on being un-American, but many land managers agree that the strict control of all fires has led to management problems in some ecosystems. Thus, the pursuance of a careful evaluation of winter precipitation management would seem to be encouraged.

Logging activity first became noticeable when the railroad was extended into the vicinity about 1860. Selected trees of about 14 inches diameter were cut for railroad ties, a practice known as "tie-hacking." Today logging is the major industry in the mountains, and a conspicuous one as well since the clear-cutting method seems best suited for the most abundant and most valuable species, lodgepole pine. Whether or not clear-cuts adequately simulate fires in the forest ecosystem is still being debated, but certainly logging activities have replaced fire as the major source of ecosystem perturbation. Wind storms are occasionally

important. Grazing of the forest ecosystems seems to have had a minor influence, but some of the alpine meadows may have been affected by sheep. Dwarf mistletoe causes considerable perturbation to the lodgepole forest ecosystem in certain areas, but thus far the pine beetle has not been noticed to any great extent.

Considerable autecological information is available for the trees of the Medicine Bow Mountains, too much to be summarized in this report. A few observations, however, are relevant to precipitation management. First, with regard to moisture requirement, spruce, fir, and aspen seem most demanding when in the seedling stage. Mature trees can tolerate considerable stress, but seedling establishment is the critical phase of the life cycle. Bates (1923) found that spruce seedlings depleted soil moisture more rapidly than lodgepole, and this may explain the greater water requirement by spruce. Ronco (1970) decided that seedling establishment of Engelmann spruce is sporadic because often the seed bed is too dry by the time it is warm enough for germination. Except for lodgepole pine, those species requiring the most moisture are also the most abundant in the planned target area, especially spruce and fir. Whether cloud seeding will stimulate or retard the growth of these species will depend on exactly how precipitation management affects the climate and length of growing season, and whether the trees are in fact most limited above 9,000 feet by water availability, soil temperature, length of growing season, or nutrients. Whether seedling establishment is favored would again depend on the actual effects of cloud seeding and on the current limiting factors for seedling establishment on various sites in the mountains. As Waggoner (1966) and Whittaker (1967) have pointed out,

a change in the moisture regime could affect rates of succession and community composition; the mechanism is understood only with a knowledge of limiting environmental factors and the actual effects on the environment resulting from precipitation management. Our research is not focused on the trees, but we are trying to understand the limiting factors controlling the forest understory, meadow, and tundra vegetation.

Another aspect of the coniferous trees at high elevations is their susceptibility to the brown-felt fungus (Neopeckia coulteri (Peck) Socc.), which grows in snow banks and is known to kill seedlings. We have initiated experiments to evaluate the effect of increased snow on infection rate of Lodgepole pine by the brown-felt fungus, and hope to determine whether more snow would increase the liklihood of infection. Snow-molds are also of interest in this regard, though it is not known that they are a problem for seedling establishment.

The zonation of the forest vegetation in the Rocky Mountains has been summarized by Moir (1969). He suggests that lodgepole forest is not always a pioneer community, forming a climax where spruce and fir are unable to grow (Figure 2). He suggests the recognition of a climax lodgepole pine forest zone between 8,200 and 9,300 feet elevation. Moir's study was done primarily in Colorado, but his suggestion seems appropriate for the Medicine Bow Mountains where some lodgepole stands appear to be climax. The elevational delimitation may not be appropriate, however, especially since our observations would agree with others who suggest that slope and exposure have a greater influence on plant distribution than elevation.

Above Moir's lodgepole zone is the subalpine spruce-fir zone, the classical climax for the Rocky Mountains occurring just below timberline.

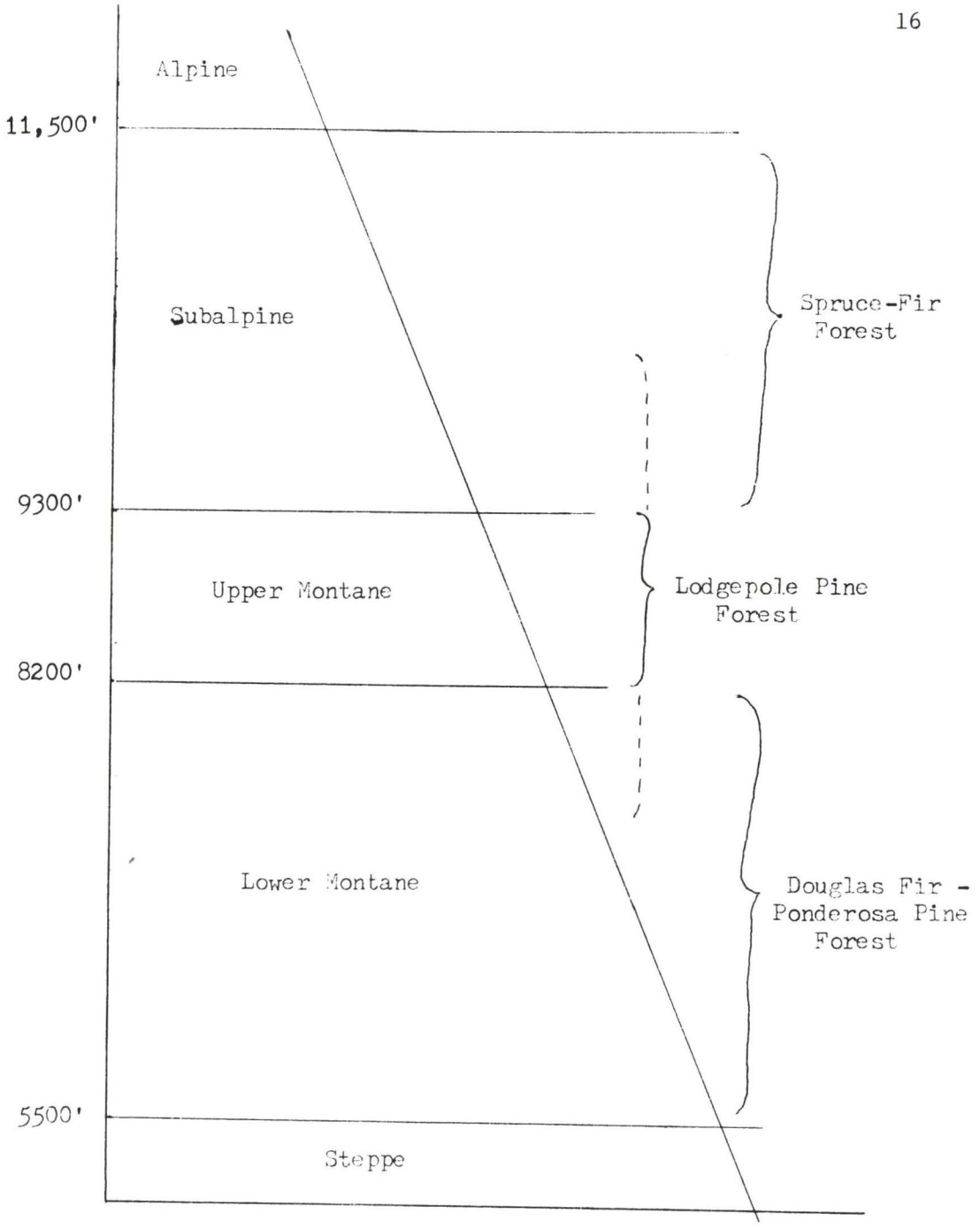


Figure 2. Vegetation zonation in the Wyoming-Colorado Area of the Rocky Mountains, modified after Moir (1969).

This zone accumulates more snow than any other, to some extent due to snow being blown off from the windswept tundra above. Lodgepole forests occur in this zone also, but they are definitely seral. Stahelin (1943) has summarized the possible successional sequences for subalpine forests following fire in Colorado, and the same sequences seem possible in Wyoming (Figure 3).

Forest primary productivity in the Medicine Bow Mountains is unknown at this time, except for wood production estimates made for lodgepole pine by the Forest Service. Wood production ranges from a high of about 45 ft^3/acre/year to a low of -7 ft^3/acre/yr.

Alpine timberline in the Medicine Bow Mountains, as elsewhere, is not easily explained. Griggs (1938) and Daubenmire (1954) have reviewed the possible explanations and no summary is necessary here. Snow is apparently of some importance in certain areas. Brink (1959) observed an advancing timberline and attributed this to less snowfall during the last century. A receding tree line with more snowfall cannot be assumed, of course, but Billings (1969) described a ribbon forest - snow glade phenomenon near timberline in the Medicine Bow Mountains, illustrating that large snow drifts can break the continuity of subalpine forests. Either forest margins or existing "ribbon forests" function as snow fences causing the accumulation of snow in the forest or snow glade, as the case may be. If the snow drift in the forest persists until late summer, the trees may die; or in the case of the snow glade drift, seedlings do not become established. The snow glade on the east edge of Cinnibar Park in the mountains had snow until August 6, in 1972. Long persisting drifts either shorten the growing season below a certain threshold, or create soil conditions that are intolerable to the seedlings. Brown-felt fungus is also very frequent on seedlings that do occur occassionally in the snow glade.

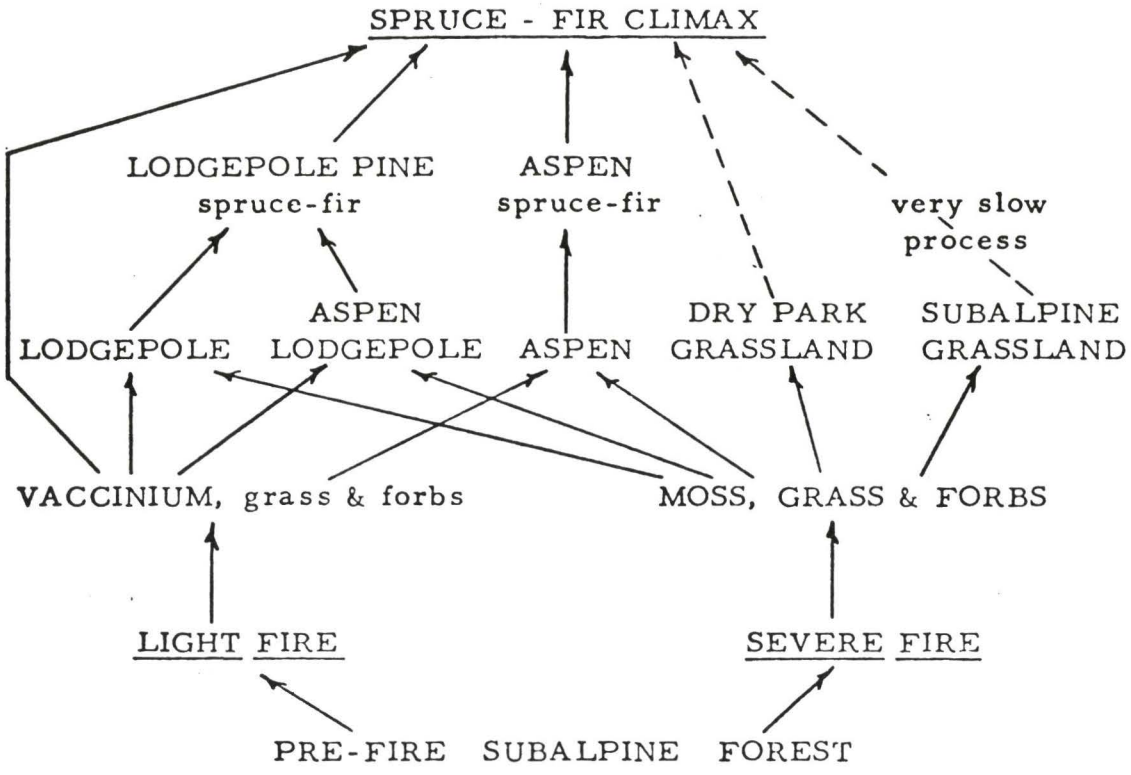


Figure 3. Predominant secondary successional trends in subalpine forest of the Central Rocky Mountains following light and severe forest fires (Diagram from Stahelin, 1943).

The Snowy Range area of the Medicine Bow Mountains has been the site of many studies on alpine ecology, some of which seem quite relevant to precipitation management. For the purposes of our project, we consider the 11,000 feet (3,333 m) contour as the approximate lower limits of the alpine zone in the Medicine Bow Mountains. The true alpine zone, therefore, does not cover a large area. A rough estimate would be about 6 or 7 square miles (16-18 sq. km).

Vegetation in the alpine zone is quite variable, and many ecologists consider a vegetation classification based on only species composition to be extremely arbitrary. Classifications based on the physiognomy of the vegetation and site factors can be more easily constructed, for example the following:

1. Shrub communities.
    a. Willow (Salix planifolia) thickets. This type occurs along stream courses and in areas of semiriparian environment and deep winter snow cover.
2. Graminoid communities.
    a. Sedge bogs (Carex and Juncus spp.), found along the edge of lakes and ponds, and in areas advanced in hydrarch succession.
    b. Wet meadows. This community type is found in areas slightly less moist than the sedge bogs, such as in areas below long-lying snowbanks which receive considerable meltwater during the growing season. Carices and grasses are the dominant taxa. Tufted hairgrass (Deschampsia caespitosa) is particularly evident.
    c. Dry meadows. Present on the less well-watered sites. Species composition mainly grasses, but carices and forbs also are common.

Tufted hairgrass and alpine bluegrasses (Poa spp.) are the dominants. The Kobresia meadow community common in the alpine zone of Colorado does not occur in the Medicine Bow Range.

3. Forb communities.

   a. Forb turf, present on still dryer sites than the graminoid communities. The most common taxon is alpine avens (Geum rossii). A great many other forbs are present. Species of alpine clover (Trifolium spp.), alpine sagewort (Artemisia spp.), bistort (Polygonum spp.) and other flowering, broadleafed plants are common and may dominate a given site. Tufted hairgrass is also quite common.

   b. Cushion plants. This community is present on the driest sites, especially in areas of windswept terrain. Plants have a caespitose growth form. Many species are present but phlox (Phlox spp.), alpine clover, and moss campion (Silene spp.) are generally dominant. Dwarfed graminoid taxa common to the graminoid-dominated communities are most common.

Within the subalpine zone are many large areas of herbaceous vegetation, commonly called "parks". Less is known of the taxa composition although many of the species which are present in the alpine zone also occur here in abundance. Tufted hairgrass is particularly prevelant and for the purpose of this paper can be considered the definitive species for this zone. At lower elevations big sagebrush (Artemisia tridentata), and Idaho fescue (Festuca idahoensis) are common species and are often bordered or intergrade into quaking aspen (Populus tremuloides) woodland.

As can be seen from the above outline, a great deal of floristic gradation is present between communities. This is due mainly to gradations in available moisture which appears to be a major environmental

factor in the alpine zone. It must be remembered that, in general, the alpine zone is a dry area for plant growth in spite of the fact that it receives considerable precipitation (24-29 inches or 600-740 mm in the Medicine Bow Mountains). Most of the precipitation is in the form of snow and the soil may be frozen for long periods. This, combined with the extremely windy conditions (25-30 mph or 40-50 km/hr winds are generally constant through the winter period) leads to extremely dry conditions during most of the year. Thus, much of the moisture is in a form unavailable for plants or is transported away from the alpine zone. These factors, combined with low temperatures, tend to limit plant growth. Limited plant growth combined with the weathering-resistant geological material (Precambrian metaquartzite in general) and high winds also limit soil development in many areas of the alpine zone.

While the alpine zone of the Medicine Bow Mountains is not extensive it has been intensively studied, primarily by Billings and his students.

Bliss (1956) studied the relationship between alpine plant growth, as measured by stem elongation and leaf expansion, and the following environmental factors: (1) solar radiation, (2) air, surface and soil temperatures, (3) precipitation, (4) vapor pressure deficit, (5) wind, and (6) soil mositure. He found only low correlations between air and soil temperatures and stem elongation.

Billings and Bliss (1959) made a 2 year (1954 and 1955) study of the vegetation associated with a single snowbank in the Snowy Range section of the Medicine Bow Mountains. They sampled two locations--above and below the snowbank--at weekly intervals. Maximum total above-ground standing crop on the upper area varied from 27.0 g/m^2 to 57.8 g/m^2 and usually occurred 3-4 weeks after snowmelt. On the lower site the range was 21.3

g/m^2 to 141.3 g/m^2 which occurred three to five weeks after snowmelt. Average daily productivity was 2.8 g/m^2/day on the upper site and 6.0 g/m^2 on the lower site. Often the maximum productivity was recorded immediately after snowmelt. Little difference was found in air temperature or vapor pressure deficit between the upper and lower sites and the differences in plant productivity were thought to be the result of the amount of available soil mositure and the length of time the plants were released from snow cover.

Scott (1963) made the most detailed study of the relationships between standing crop, primary productivity and environmental factors in the alpine region of the Medicine Bow Mountains. He found above-ground standing crop to vary from 14 to 348 g/m^2, with most sites (29 of 50) between 100 and 200 g/m^2. His statistical analysis indicated the following were important environmental variables: (1) altitude, (2) estimated winter snow cover, (3) estimated moisture regime, (4) estimated soil movement, (5) extractable K, (6) available water in the subsoil. Factors 2, 3, 4, and 6 could be affected by winter precipitation management.

With regard to primary productivity, Scott estimated 11.1 g/m^2/day for a mesic site and 1.2 g/m^2/day on a xeric site, both estimates being average values for a 6-week period in June and July 1962. Weekly total productivity on the mesic site was correlated with: (1) weekly solar radiation, (2) weekly air flow, (3) soil temperature and (4) soil moisture. Only solar radiation was correlated with weekly total productivity on the xeric site and this was significant only at the 10% level. Scott attributed this lack of correlation "to the low accuracy of the xeric station data", masking any correlation with environmental factors.

Smith and Johnson (1965) investigated the standing crop of three subalpine parks in the Medicine Bow Mountains. They found maximum standing crop to occur as early as July 1 and to consistently occur by late July. Maximum standing crops ranged from 63.8 g/m^2 on the least productive site to 280.2 g/m^2 on the most productive site. Although they do not present data for productivity, this can be determined from the information they did provide. On the basis of a 30-day growth period prior to the time of maximum standing crop, the least productive site would have a productivity of 2.1 g/m^2/day while at the most productive site the rate would be 9.3 g/m^2/day. No micrometeorological data were collected in this study.

(continued on next page)

Smith (1969a) measured the above ground standing crop on 29 sites at or above timberline in the Medicine Bow Mountains. The average above-ground standing crop was 60.3 g/m^2 with a range of 7.8 to 115.7 g/m^2. Two species, Deschampsia caespitosa and Geum rossii produced 23% of the herbage sampled. Production of herbage was found to be most significantly related to the silt and clay content and pH of the A horizon, and slightly less significantly related to the organic matter content of the A horizon and the extractable potassium in the solum. Geum rossii was most common on coarse textured soils of high organic content and Deschampsia caepitosa tended to occur on the more finely textured soils of relatively low organic content. Smith also indicated the moisture content of the soil influenced the distribution of these two species, but he did not measure this factor, basing his assumption on the presence of glei horizons and the degree of mottling, both of which tend to indicate wet soils. Deschampsia caespitosa was more prevalent, but not confined to soils with the above "wet" characteristics.

An apparent frost hummock-sorted polygon cycle was described by Billings and Mooney (1959) in the Libby Flats area. Their results indicate that wind erosion and frost thrusting can cause degradation of mature peat hummocks through frost scars to sorted polygons (frost boils). The rocks which are thrust through the scar from below form the intervals of the sorted polygons while waterlogged silt forms the centers. Subsequent drowning of the sorted polygons by a rising water table allows the invasion of Carex aquatilis on the rocky intervals. Small peat mounds are initiated here which may grow larger by slow accumulation of peat. Later, freezing and thawing increase the rate of expansion of the hummocks

until they may be snow-free at critical times in the winter. Blasting by snow and ice particles in strong winter winds produces frost scars on the crests of the hummocks and degradation starts. Thus it appears that these phenomena are parts of a natural cycle in which "climax" tundra on the mature mounds is really only temporary.

Mooney and Billings (1960, 1961) studied the carbohydrate cycle of three alpine species (Saxifraga rhomboidea, Polygonum bistortoides and Geum rossii) from the beginning of one growing season until the start of the following one. Analyses were made of the carbohydrate content of roots, rhizomes and shoots of these alpine tundra species. Results were correlated with phenological events as observed in the field. Growth of these plants was found to be very rapid, commencing in some instances under a cover of old snow. The underground organs contained relatively large amounts of carbohydrate reserves. A great part of this stored carbohydrate was utilized in growth prior to snowmelt and during the period of rapid shoot growth immediately following snowmelt. In Polygonum, 50% of the rhizome reserves was used in a one week period during early growth. Except for this short period of rapid depletion in rhizomes and roots during early growth, high carbohydrate levels were maintained both in the shoot and in the underground organs during most of the growing season. Generally, the lowest carbohydrate reserve level in both root and shoot occurred before flowering, a relatively high level was maintained in the shoot from flowering until after fruiting, while peak storage in underground parts was reached at the start of fall dormancy. The carbohydrate cycle in these alpine plants is quite similar to that in certain arctic plants.

In their 1965 paper, Mooney and Billings studied the effects of altitude on the carbohydrate content of several species. Sugar and starch contents of roots or rhizomes of Polygonum bistortoides, Saxifraga rhomboidea, and Calyptridium umbellatum were measured at different altitudes in the Sierra Nevada of California and in the Medicine Bow Mountains of Wyoming. Carbohydrate reserves appear to be higher near the lower altitudinal limits of a species. Polygonum bistortoides, Caltha howellii, and Sibbaldia procumbens transplanted to lower and warmer elevations used up stored carbohydrates more rapidly than at the elevation of origin. The higher carbohydrate content of individuals in natural populations near the lower altitudinal limits of an alpine species thus appears to be an ecotyple or ecoclinal adaptation.

Field measurements of photosynthesis and respiration rates of whole alpine plants in situ were made at an elevation of 3,307 m in the Medicine Bow Mountains, Wyoming, using an infrared gas analyzer by Billings et al (1966). Most measurements were for periods of 30 minutes to two hours but two "whole-day" measurements lasted from before sunrise to after sunset. Maximum net photosynthesis rates ranged from 4.15 to 13.4 mg CO_2/dm^2 two surfaces/hr with an average rate of 9.32. An all-day measurement on Geum rossii during somewhat cloudy weather showed net photosynthesis paralleling and responding to changes in light and temperature. Similar measurements of Polygonum bistortoides in clear sunny weather showed a midday depression in net photosynthesis, due perhaps to high leaf temperatures under intense solar radiation. Net photosynthesis of whole sod blocks averaged 6.23 mg CO_2/g dry wt/hr . Soil CO_2 output averaged 1.846 mg CO_2m^2/hr which they report as higher than published results from

lower altitudes. Rough estimates of dry weight gain as calculated from sod-block metabolic rates average 2.79 g dry wt/m^2/day. Measurements of CO_2 concentration in ambient air were also made. Morning observations averaged 0.430 mg/l while afternoon measurements averaged 0.387 mg/l. The lower afternoon values probably reflect photosynthetic activity of the surrounding forest vegetation on the lower slopes.

Scott et al (1970) studied the CO_2 exchange rates of several subalpine graminoids and forbs from the Medicine Bow Range. Multiple regression analysis showed that CO_2 exchange of shoots of subalpine meadow plants, as determined by field measurements, was correlated with light and some aspect of moisture regime (either leaf relative turgidity or soil moisture), but not with temperature.

Another study in which material or measurements from the Medicine Bow Mountains was used, was that of Bonham and Ward (1970). In their work on the phytosociology of tufted hairgrass (Deschampsia caespitosa), they used frequency data for association analysis of species. On the basis of species associations it was evident that the structure of alpine meadow vegetation with hairgrass varies in a subtle fashion, related environmentally to a moisture gradient.

Water content of alpine plants in the Medicine Bow Mountains was studied by Hill (1964) to determine the water relationships between these plants and their environment, where climatic conditions are characteristically severe. Plants of two areas near timberline were studied. At Libby Flats leaves were taken from Geum rossii, Polygonum bistortoides, Trifolium parryi and Polemonium viscosum; and at Brooklyn Lake, leaves were collected from Geum rossii, Polygonum bistortoides, Pedicularis parryi and Pedicularis groenlandica. A general diurnal pattern of leaf

water content appeared throughout the study. Analysis of diurnal patterns of water content and environmental variables indicated that the daily patterns of water content were established through the control of transpiration rates by temperature and relative humidity. Effects of the intensity of solar radiation and wind velocity on daily variations of water were negligible. Although low values of water content were observed, plant wilt was not apparent. Seasonal patterns of water content were expected to be controlled by seasonal trends of soil moisture and the seasonal progression of plant development. Although soil moisture varied considerably throughout the season, water content patterns of plants in both areas remained remarkably constant throughout the growing season until late August. Soil moisture did not appear to affect the seasonal trends of water content of the plants studied and apparently was not a limiting factor of absorption rates. Although soil moisture values decreased substantially at times throughout the growing season, plant wilt was not observed and it is doubtful that soil moisture ever decreased to the permanent wilting precentage. Leaf water content remained nearly constant for all species during the stages of vegetative growth, flowering, and fruit development, but it decreased sharply with the commencement of seed formation and senescence of aerial organs of the plants. Environmental variables were somewhat alike throughout the season at Libby Flats and Brooklyn Lake, and leaf water content, a response to environmental and intrinsic variables, was similar in value and pattern for species in both areas. Hill found that although soil moisture probably did not limit rates of absorption, atmospheric factors determining transpiration rates were severe. These plants demonstrated a remarkable capacity to

tolerate large diurnal variations of water content without apparent wilt. The plants' adaptations to the severity of the alpine environment are reflected in this ability to withstand large fluctuations in water content.

In summary, there is a rather large body of information on the vegetation that is relevant to precipitation management. Specifically, whatever we can glean on moisture relations, carbohydrate balance, and limiting factors will permit more confident predictions on the possible effect, if any, of more snow. This information will be incorporated into our final report.

GENERAL RESEARCH DESIGN

At least four approaches can be identified for evaluating the ecological impact of weather modification:

1. controlled large-scale experiment approach.
2. controlled small-scale experiment approach.
3. before-and-after monitoring approach.
4. systems analysis approach.

The discussion that follows describes briefly a rationale that has been useful for determining the best approach for each of the seven studies that are part of the Medicine Bow Ecology Project.

Controlled large-scale experiment approach

An ideal option would seem to be the location of two very comparable watersheds, one of which would be seeded to increase snowfall and the other not seeded. After considerable discussion, this approach was essentially abandoned for the following reasons. First, it seemed doubtful that a legitimate control of watershed size could be found. Two areas of several square kilometers would most likely be too different in microclimate and vegetative cover, so that differences that occurred after the treatment probably could not be attributed confidently to the snow-treatment effect. Secondly, because the treatment effect could possibly be difficult to detect in a short time, several field seasons would probably be required just to select the two "comparable" watersheds. Careful measurements would be required from a large number of watersheds before the best combination could be arrived at. Thirdly, the best two watersheds for

such an experiment would probably be adjacent, and there is the question of whether a cloud seeding operation could prevent artificial precipitation on the control. Because of these problems, the Medicine Bow Project has focused more on small-scale experiments, where controls can be more easily established.

Controlled small-scale experiment approach

The advantage of this approach is that controls are more easily located and replications are possible (assuming plots no larger than 10 m^2 in our area). The snow treatment, of course, must be applied in some manner other than seeding, but meaningful data can be obtained for some organisms, in particular small plants and micro-organisms. Analysis of variance (randomized complete block design) can be used to evaluate treatment effect with a certain degree of confidence. This approach is being utilized in the Medicine Bow Project where it seems promising, but it does not seem suitable for large plants and most animals. With careful measurements it may be possible to determine the effect of a snow treatment after 3 years.

Before-and-after monitoring approach

This approach is desirable because no control is necessary and actual cloud seeding provides the snow treatment. It would seem to be a desirable phase of any impact study and it is considered to be an important approach for the Medicine Bow Project. The disadvantages are that the impact is not known until its happened over a large area, which seems like a poor management approach, and there is often the question about whether the changes that occurred after the cloud seeding were in fact caused by the seeding or some other natural phenomenon. In the case of winter precipitation

management this problem is especially possible because the secondary ecological effects are not likely to be observed for several years. The ecosystems are already adapted to considerable year to year fluctuations in snow fall, so the changes will probably result from a modified mean annual snowfall or a modified sequence of heavy and light snowfall-years.

The systems analysis approach

This approach depends on developing statistical or mathematical models of the natural systems that would be subject to weather modification. The models can then be used to predict how the system or sub-system might respond to the treatment. This approach obviously requires a considerable amount of data, some of which may come from direct observation and correlation analysis, and some of which may depend on the experimental approach discussed above. Also, it is known from IBP experience that the total system cannot be modeled without considerably more financial input than is available for impact studies. Despite these problems, the systems analysis approach is being applied at several levels in the Medicine Bow Project. At one level we are simply working toward an understanding of the Medicine Bow ecosystems that will allow us to predict the degree of impact, if any, of winter precipitation management on certain key components and processes; at another level we are developing, wherever possible, statistical and mathematical models of sub-systems that presumably will yield greater understanding and provide greater predictive power for evaluating impact.

All of the four approaches described above are operational to some degree in one or more of the seven separate studies of the Medicine Bow Project. Which approach is emphasized for each should be clear from the research descriptions.

IMPACT OF SNOW ON HERBACEOUS AND SHRUBBY VEGETATION

Thilenius, Knight, Kyte, Rogers, and Starr

A dominant feature of the terrestrial ecosystems is the vegetation; if the vegetation is modified by winter precipitation management, then other ecosystem features may be modified as well. With this in mind a variety of studies have been initiated to evaluate the effect of snow cover on the herbaceous and small woody vegetation of the Medicine Bow Mountains above 9,000 feet. The San Juan Ecology Project has a similar program underway for the tree component.

This phase of the Medicine Bow Ecology Project can be sub-divided as follows, with the name of the responsible investigator listed with each sub-project:

1. Mapping and remote sensing to evaluate vegetation response to snow cover - Knight and Rogers.
2. Environmental factors affecting the species composition and productivity of alpine tundra on Medicine Bow Peak and high subalpine meadows on Libby Flats - Thilenius
3. The effect of a snow treatment on subalpine meadow and forest understory vegetation - Knight and Kyte
4. The effect of certain environmental factors (including snow cover) on forest understory species composition - Rogers and Knight
5. The effect of certain environmental factors (including snow cover) on a meadow complex in Headquarters Park - Starr and Knight
6. The autecology of Vaccinium scoparium - Kyte and Knight

Mapping and Remote Sensing to Evaluate Vegetation Response to Snow Cover (Knight and Rogers)

Mapping in our program is used only to document current vegetation boundaries on various sites, thereby providing a basis for documenting shifts in boundaries that may occur after cloud seeding begins. Thus, this phase of our program is purely descriptive at this time and will become most valuable after several years, if not decades. Some boundaries could shift within a few years, but most shifts would probably require a longer period of time. Our other studies will provide a basis for deciding whether shifts that do occur, if any, can be attributed to increased snow.

Mapping has begun on portions of two watersheds, the upper South Brush Creek area around Headquarters Park and the upper South French Creek area near Libby Flats. These areas were selected because they are above 9,000 feet elevation and in the center of the proposed target area, because considerable boundary edge occurred within these areas, and because the major vegetation types are contained within these areas. The mapping is being done at three levels:

1. Aerial photographs and U.S.G.S. topographic maps will be used to map the forest canopy of each area, both of which are about 4 to 5 square miles. Existing U. S. Forest Service vegetation maps are being consulted as well as the photographs.

2. A 10,000 m^2 permanent plot in each area has been delimited and is being mapped for tree canopy cover on a much larger scale.

3. Within each of the 10,000 m^2 plots, four permanent plots, each 1 x 10 m, are being mapped at a resolution of one square decimeter. Species that cover 15% of more of each square decimeter are being recorded, for example see Figure 4. The rectangular plots themselves extend across herbaceous vegetation boundaries in several cases. Photographs are being taken of each square meter along the 1 x 10 m plots.

Some of the mapping work is completed, but since the maps serve no immediate need they are not included in this Interim Report. Any future shifts in vegetation boundaries within these two areas, and to some extent species composition, for whatever reason, will be easily detectable by reference to the maps now being prepared. Remote sensing data will be utilized to monitor seasonal changes of snow cover and vegetation condition on portions of the upper South French Creek and upper South Brush Creek watersheds. Arrangements are now being made to have color infrared aerial photographs taken at three times during the next growing season--early June, late June, and mid-July. The purpose of these photographs will be to further document existing boundaries, but over a broader area than we can reasonably map; and to gain experience with the utilization of this kind of remote sensing for evaluating the effect of snow duration on vegetation. In addition, we are cooperators with NASA and have access to the ERTS satellite imagery that is taken over Wyoming every 18 days. We will try to determine the utility of this satellite imagery for monitoring snow cover and vegetation condition in the Medicine Bow Mountains. An iso-densitometer, multi-band scanner, and other equipment are available in the University of Wyoming Remote Sensing Laboratory (Department of Geology). This ERTS satellite imagery will be examined at no expense to the Project.

August 3, 1972
HEADQUARTERS PARK
PLOT #3 SECTION #6

KEY TO THE SPECIES

ALA - Abies lasiocarpa (Hook.) Nutt.
EP - Erigeron perigrinus (Pursh.) Greene
HG - Hieracium gracile Hook.
PA - Poa alpina
PJ - Polytrichum juniperinum Hedw.
PT - Plantgo tweedii Gray
SP - Sibbaldia procumbens L.
VS - Vaccinium scoparium Rybd.

DIRECTION 343° MAG.

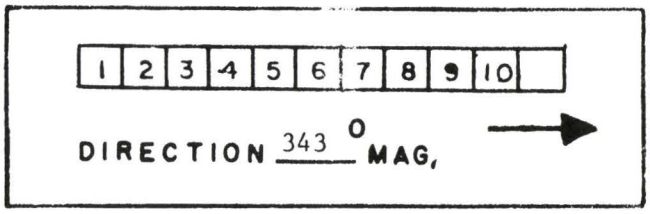


Figure 4. An example of the data recorded in each dm^2 of each m^2 in the 1 x 10 m plots.

1 SQ. METER

HG VS PJ	HG VS	EG	HG PJ EG	HG PJ		HG PJ	ALA HG	HG	HG
HG VS PJ	HG VS	EG HG		HG	HG	HG	HG PJ	HG	EP HG
PJ VS	HG		HG PJ	HG PJ	HG PJ	HG	HG PJ SP	PJ SP	HG PJ VS
HG PJ	HG PJ PA	HG PJ	HG PJ	HG PJ	HG PT	PJ	HG PJ	HG PJ	PJ
HG PJ	HG PJ	PJ		HG PJ	PT	HG PA	PJ	PJ	PJ
HG PJ	SP PJ	HG PJ	PJ VS	PJ	PJ	HG PJ	HG PJ	HG PJ	HG PJ
HG PJ	PJ	PJ	PJ VS	HG PJ	SP PJ	HG PJ VS	HG PJ	HG PS	ALA HG
PJ	PJ	HG PJ	VS PJ	VS	PJ	HG PJ	PJ	HG PJ	HG ALA EB
HG PJ	HG PJ	HG PJ	HG PJ	HG PJ	VS	VS	HG PJ	PJ	PJ
HG PJ	HG PJ	HG PJ	HG PJ	HG PJ	HG PJ	PJ	PJ	HG	PJ SP

Environmental Factors Affecting The Species Composition And Productivity of Alpine Tundra on Medicine Bow Peak and High Subalpine Meadows on Libby Flats

(Thilenius)

This particular phase of the study involves U. S. Forest Service Research Work Unit 1703 and is concerned with the ecological relationships of high-elevation herbaceous plant communities and their abiotic regime. The objectives of the study are to determine basic plant-environment interactions in high elevation ecosystems and to provide an ecological benchmark, or baseline, from which the effects of man-caused environmental changes such as cloud seeding can be measured.

The research area is located 64 km west of Laramie, Wyoming, in the Snowy Range section of the Medicine Bow Mountains. Three study sites were located in the alpine-subalpine region (+3200 m elevation). Two are in true alpine tundra, the other in a subalpine grassland.

Libby Flats. The Libby Flats site is located in the NW1/4 NW1/4, S29, T16N, R79W, at an elevation of approximately 3230 m on a gentle (3 - 6%) north-facing slope. The vegetation is an alpine turf community dominated by Geum rossii. The site can be reached by automobile after snowmelt.

Lake Marie. The Lake Marie site is located in the center of S13, R80W, T16N. Elevations range from approximately 3450 to 3475 m. Exposure is west and slope angles are from 16% on the lower portion of the area to 10% on the upper part. The site is disected with numerous stone stripes and boulder fields. The vegetation is similar to that of the Libby Flats site. The site is accessible only by foot or horseback during the summer

since it is located in an area prohibited to motorized vehicles during the snow-free period. It can be reached by over-snow vehicles when sufficient snow is present.

Fourlog Park. Fourlog Park is located in the SW1/4, NE1/4, S5, T15N, R79W. The elevation of the site is 3140 m. The slope is very gentle (3 - 4%) and faces east. The site is surrounded on three sides by forest and the vegetation is a subalpine grassland. The Fourlog Park site can be reached by automobile after snowmelt, but since much of the road is in the forest where the snow remains after the park itself is snowfree, early season access is by foot only.

Sampling Design

Five sample units were located on each sample site. Each consists of a randomly-located 5 x 14 m plot. Within this plot, two 1 x 12 m areas are reserved for sampling the vegetation. These areas are separated by a 1 m wide interval to avoid trampling. A 1 m wide exclusion zone also surrounds the sampling areas. Each of the two sample areas within the plot is subdivided into 120, 20 x 50 cm quadrats (0.1 m^2) for a total of 240 quadrats/sample unit. Plots are protected from livestock grazing by a two-strand electric fence.

Microclimate Sampling

At each of the five sample units on each site, data are collected during the growing season (ca. June-September) on the following microclimatic variables:

1. Air temperature and relative humidity. A continuous record of these variables is obtained from a hygrothermograph with the sensing ele-

ments at +20 cm above the ground surface. The hygrothermograph is enclosed in a small, double-roofed, weather screen (Hungerford, 1957) which is securely fastened to the ground. Standard max-min thermometers on a Townsend Support are also mounted in the weather screen.

2. Precipitation. A 20 cm diameter non-recording rain gage with the orifice at +30 cm is located on each sample unit to record growing season precipitation. Snow depths are gauged from permanently fixed 2 m high posts (3 m in Fourlog Park) divided into 2 dm intervals by alternate orange and black painted subdivisions. Rain gages are read at seven-day intervals during the growing season. Snow depths will be recorded at monthly intervals starting in January 1973. Depth and density of the snowpack is determined at these times with a standard King tube snow-probe.

3. Soil temperature and soil moisture. These variables will be recorded at periodic intervals at depths of -5 and -20 cm using thermocouple psychrometers. Difficulties were encountered with these instruments in 1972, so some soil moisture data were obtained with the gravimetric method. Additionally, a three-pen thermograph has been installed at the Libby Flats site to provide a continuous record of soil temperature at -5, -20 and -50 cm. This machine will be in operation throughout the entire year.

In addition, one of the sample units on each site was equipped with instruments to measure the following microclimatic variables:

a) Incoming solar radiation. A pyranograph mounted at +30 cm is used to record this variable.

b) Air flow. A three-cup totalizing anemometer mounted at +50 cm records this variable. This instrument is also equipped with a recording

device that will give a continuous record of wind speed.

Edaphic Factors

A description of the soil morphology is made at each sample unit. The standards of the Soil Survey Staff (1960) will be followed. In addition, laboratory determinations will be made of the following:

1. Particle size distribution
2. pH
3. Moisture tension (1/3, 15 atm)
4. Bulk density

Methods are those recommended by the Soil Survey Staff (1960).

Vegetation Sampling

1. Composition, frequency and phenology. Species composition, frequency and phenological stage are sampled at two-week intervals on each study site. Twenty five $0.1m^2$ quadrats are randomly selected at each sample date (five quadrats in each sample unit). The canopy coverage estimation method developed by Daubenmire (1959) is used to record the coverage and frequency of each taxon.

The phenological development of each taxon present in a quadrat is determined on the following 12 category scale.

1. Seedling
2. Vegetative
3. Bud
4. Early bloom
5. Full bloom
6. Past bloom
7. Fruit
8. Ripe seed
9. Fall color
10. Cured
11. Dormant
12. Standing dead

2. Biomass. The intimate association and small size of the plants to be sampled and the harsh environment (strong winds, cold temperatures) made field harvesting of the quadrats a very imprecise and difficult procedure. Consequently, all biomass samples are collected by removing a

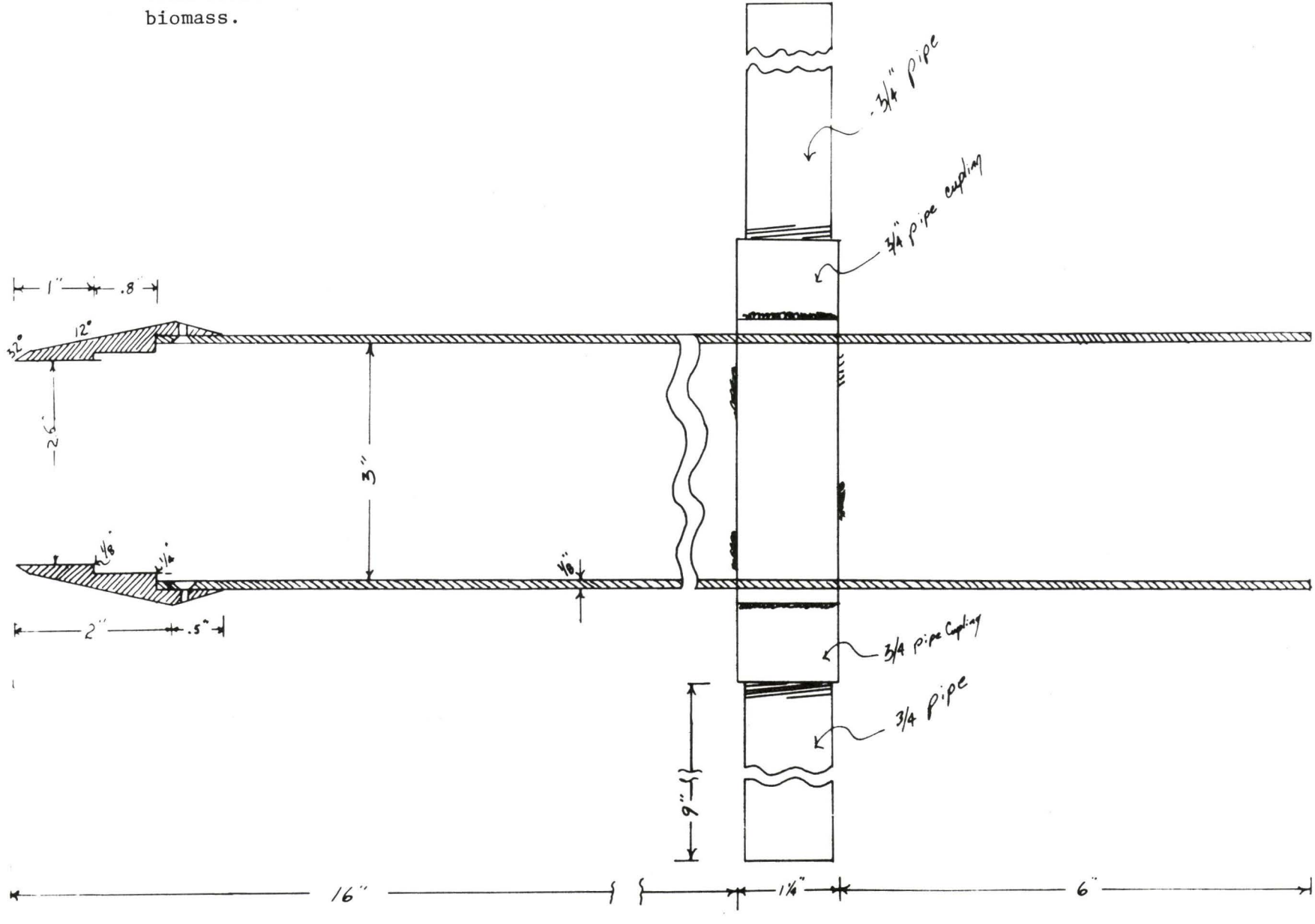
cylindrical core of soil, root material, litter and above-ground vegetation. A coring device has been developed (Figure 5) for this purpose. The cores are enclosed in a capped plastic cylinder to facilitate transfer and storage and to minimize drying. They are frozen for storage.

The present sample consists of 125 cores from each site at two-week intervals. The cores are taken in groups of five from the five randomly located 0.1 m^2 quadrats in each of the five sample units at each site. Cores are removed after the estimation of taxon coverage, frequency and phenological stage. The technique is to insert the corer until a rock is hit. No attempt is made to go deeper. Cores as long as 50 cm have been extracted. Examination of the soils indicates the majority of the root biomass is concentrated in the upper 20 cm of the soil profile. The statistical adequacy of our sample will be tested as soon as all cores have been washed and separated by species.

A machine to separate the root biomass from the soil has been constructed (Figure 6). This machine operates on the same principle as that used by the I.P.B. Grassland Biome. A general outline of the technique is as follows:

1. Thaw the core.
2. Remove the above-ground vegetation, sort it to taxa, oven-dry and weigh each taxon to obtain a measure of above-ground biomass by taxon.
3. Remove the litter layer, oven-dry, weigh, ash in a muffle furnace and reweigh to correct for any incorporated inorganic material.
4. Break up the soil-root cylinder to facilitate water penetration,

Figure 5. Diagram of the device used to remove soil cores for estimtation of root biomass.



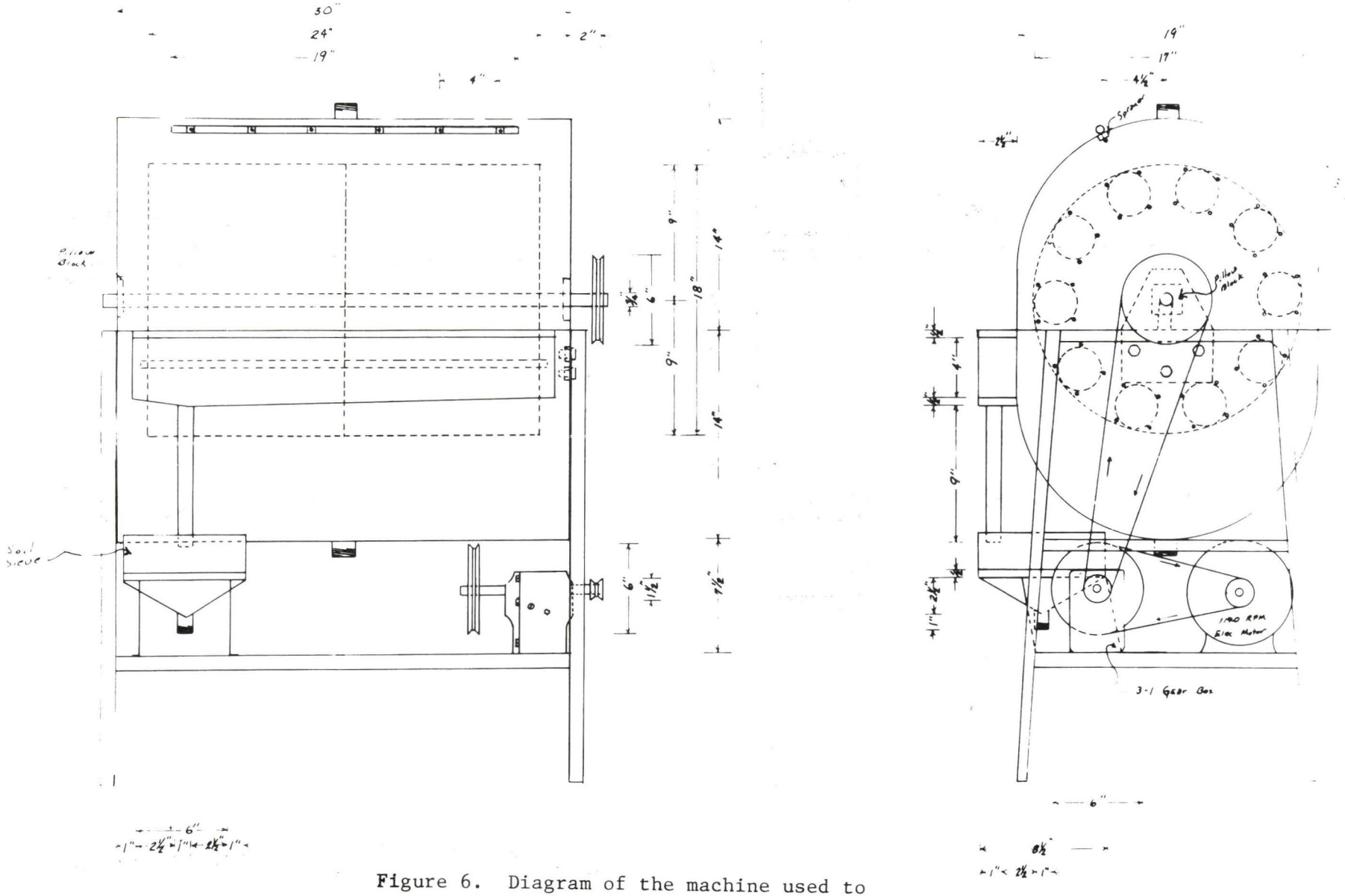


Figure 6. Diagram of the machine used to separate roots from soil.

place this material in the machine, wash until the soil is removed (ca. 20-30 min.), oven-dry the root material, weigh to obtain a measure of below ground biomass, ash in a muffle furnace and reweigh to correct for inorganic material.

No attempt is being made at the present time to identify the root material to species.

PRELIMINARY RESULTS

Microclimate

The data presented are those collected on the sample units at each site which have the full microclimate instrumentation (air temperature, relative humidity, precipitation, solar radiation, air flow, and soil temperature, Libby Flats site only). As presently available these data represent only summaries. Any discussion of differences or similarities will thus be based on subjective evaluation alone.

1. Air temperature. Maximum air temperatures at the Lake Marie site (ca. 3450 m) are from 1 - 3° C cooler than at either Libby Flats (3230 m) or Fourlog Park (3140 m). However, minimum air temperatures at the Lake Marie site are 2 - 3° C warmer than those at the other two sites. Between 7/10/72 and 8/20/72 the mean minimum air temperature at Lake Marie ranged from 5.6 to 7.7° C, with two seven-day periods where the average minimum temperature exceeded 7.0° C. This high level of average air temperature was not reached at the other two sites. Freezing air temperatures were reached at Lake Marie on only nine of the 106 days of record. At Libby Flats freezing air temperature was reached on 15 days during the same period and at Fourlog Park on 24 days during an 86 day period.

The highest mean maximum air temperatures were 24.3° C at Libby Flats

and 24.5° C at Fourlog Park. During the same seven day period the mean maximum air temperature at the Lake Marie site was 22.0° C. The highest daily maximum air temperatures recorded were 27.0° C at Fourlog Park (7/30/72), 27.0° C at Libby Flats (8/11/72) and 24.5° C at Lake Marie (7/30/72).

2. Relative humidity. Maximum relative humidities were usually in the range 98 - 100% almost every night at the Fourlog Park site. The lowest seven-day mean relative humidity was 96%. This occurred during the period when both maximum and minimum mean air temperature were at their highest levels (24.5° C and 4.7° C) at Fourlog Park.

Maximum mean relative humidity at Libby Flats and Lake Marie were alike and as much as 21% lower than at Fourlog Park. However, except for the seven-day periods of 8/8 - 8/13/72 and 9/11 - 9/17/72, maximum mean relative humidity was above 85% at the two higher elevation sites. The 8/8 - 8/13/72 period was the warmest at these sites and the 9/11 - 9/17/72 the windiest.

Mean miminum relative humidities were consistently higher at Lake Marie than at the other two sites, the difference being as much as 15%. Libby Flats and Fourlog Park had similar mean minimum relative humidities, the difference usually being less than 4%.

3. Precipitation. The best seasonal comparisons can be made for the period starting on 7/2/72 at Libby Flats, 7/3/72 at Lake Marie and 7/4/72 at Fourlog Park. During this time, total precipitation was 133 mm at Libby Flats, 98 mm at Lake Marie and 136 mm at Fourlog Park. As with air temperature and relative humidity, the Libby Flats and Fourlog Park sites are quite similar in their precipitation regime. Lake Marie, on the other hand, was drier than these two sites. The highest seven-day precipitation

recorded at all three sites was during late August to early September. This came as the result of an upslope storm from the east and was in the form of mixed rain and snow.

4. Wind. As with precipitation, the data are not directly comparable between sites because of the difference in the time the totals were accumulated. Nevertheless, it is apparent that winds are much stronger at the Libby Flats and Lake Marie sites than at the Fourlog Park site. The mean values for the period 6/6/72 to 9/24/72 at Libby Flats is 10.5 km/hr, 10.0 km/hr at Lake Marie, but only 3.4 km/hr at Fourlog Park. Thus, Fourlog Park has winds only about one-third as strong as at the other two sites. This absence of wind may be partially responsible for the colder minimum air temperatures at Fourlog Park as air mixing would be minimal and cold air drainage at night enhanced.

The highest wind speeds occurred during the middle of September, particularly at the Libby Flats site where the mean for the seven-day period ending 9/17/72 was 27.7 km/hr. Although the wind was also strong at Lake Marie during this period, it averaged over 10 km/hr less at Lake Marie than at Libby Flats.

Winds were relatively calm at the Libby Flats and Lake Marie sites during August. The lowest values were recorded during the period 8/28 to 9/3/72. This occurred when an upslope weather pattern prevailed and the winds were generally from the east with cold and moist conditions prevalent.

5. Solar Radiation. The mean values for all sites during the period 6/26/72 to 9/24/72 were: Libby Flats 446 langleys, Lake Marie 463 langleys, and Fourlog Park 451 langleys. Maximum clear-sky incoming solar

radiation at Libby Flats was 713 langleys, 732 langleys at Lake Marie, and 736 langleys at Fourlog Park. During the above period Libby Flats and Fourlog Park had only ten days without considerable cloudiness and the Lake Marie site had only six days with clear skies. The pattern of cloudiness for all sites was: generally clear skies to about 1200 hr; increasing cloudiness with a maximum near 1800 hr, then partial clearing prior to sunset. The longest period of consecutive clear days was from 9/13 to 9/16/72 (4 days). Day length during this period is approximately 13 hours. Maximum light period at the summer solstice was about 15 hours at Libby Flats. The other sites were not in operation at this time, but it is doubtful if significant differences in day length occur between sites.

6. Soil temperature and soil moisture. Soil temperature data are available only from the Libby Flats site where a three-pen thermograph was installed on 7/3/72. The thermocouple psychrometers were not installed as intended due to unforseen difficulties in calibration. They should be ready for the 1973 field season. Gravimetric analysis of soil moisture will be made using some of the soil cores extracted for biomass sampling, but this has not been done as yet.

As would be expected, the -5 cm soil level showed the greatest fluctuation and range between maximum and minimum values. The highest temperature recorded at this level was 15.8° C on 8/7/72. The range in air temperatures at +20 cm on the same data was 22.0° C to 1.0° C. Minimum soil temperature did not dip below 0° C (-0.7° C) until 9/20/72 and it rose above 0° C on the following day.

The spread between maximum and minimum soil temperature at -20 cm was approximately 1 to 1.5° C. The highest soil temperature was 7.5° C

on 7/16/72; the lowest 2.0°C on 9/21/72, the same day the lowest temperature was recorded at -5 cm.

The difference between maximum and minimum soil temperatures at -50 cm was generally less than 1.0°C. Maximum temperatures were consistently around 5.0°C with a high value of 6.0°C on 8/14/72; the lowest soil temperature at -50 cm was 2.6°C on 9/21/72.

Vegetation

1. Composition, coverage and frequency. The species composition, coverage, and frequency on the three sample sites at each sampling date are given in Tables 1, 2, and 3. The coverage and frequency values are derived from estimations of 25 quadrats (0.1 m^2) at each site at each sampling date. Frequencies above 20% for the high coverage taxa indicate the number and size of quadrats is adequate for sampling the vegetation on all three sites. Coverage values vary between sampling dates because new quadrats are selected each time.

The vegetation at both Libby Flats and Lake Marie is a true alpine type dominated by forbs. Geum rossii is the most important species at both sites. The coverage and frequencies of Geum rossii are close at both sites, averaging 35.2% : 96% at Libby Flats and 43.7% : 100% at Lake Marie.

The major subordinate species are the spikemoss Selaginella densa and the forb Artemisia scopulorum. Although Selaginella densa has a slightly greater coverage at Libby Flats than at Lake Marie, the coverage values are again quite close, as are the frequencies. The same is true for Artemisia scopulorum, and it appears that, on the basis of the most common species, the sites are quite similar.

While most of the less common taxa are present at both sites,

their order is somewhat different. For example, Trifolium parryi is, on the average, the fourth most important species at Libby Flats with an average coverage of 15.2%. At Lake Marie it is ranked tenth and has an average coverage of 3.2% and a much lower frequency (30% as compared to 83% at Libby Flats).

The most important graminoid at both sites is Deschampsia caespitosa. It is fifth-ranked at Libby Flats and fourth-ranked at Lake Marie. Its coverage is similar at both sites, but it occurs with much higher frequency at Lake Marie.

Other important species at both sites are the forbs Polygonum bistortoides, Erigeron simplex and Potentilla diversifolia. The graminoids Agrostis idahoensis, Carex albo-nigra, C. ebenea are also relatively important contributors to the vegetation.

Two species of Poa, P. alpina and P. rupicola, are much more common at Libby Flats than at Lake Marie. On the other hand, the forb Sibbaldia procumbens occurs with relatively high coverage at Lake Marie, but was not sampled at Libby Flats. Conversely, Achillea lanulosa is a relatively high coverage species at Libby Flats but only of minor importance at the Lake Marie site.

The Fourlog Park site supports a considerably different vegetation than either of the other two sites. The dominant species at Fourlog Park is Carex ebenea which has an average cover of 41.4%. Carex ebenea occurs at both Libby Flats and Lake Marie, but only as a subordinate species. The same is true for the second-ranked species, Potentilla diversifolia.

A particularly distinguishing difference between Fourlog Park and the other two sites is the absence of the cryptogam stratum at

Fourlog Park. This stratum (which includes Selaginella densa) is particularly well developed at both Lake Marie and Libby Flats.

The presence of Stipa columbiana at relatively high elevations was unexpected. However, while it has relatively high average coverage, its distribution is localized, as indicated by the average frequency of 30%. Another species of Stipa, S. lettermanni, is also present at low coverage. Both occur with the same localized distribution.

Many of the less important taxa at Fourlog Park are also present at either Libby Flats or Lake Marie, e.g., Erigeron simplex, Achillea lanulosa, Deschampsia caespitosa, Sibbaldia procumbens are all rather important at one or the other of the alpine sites. Other species which are only of minor importance at the alpine sites are relatively high ranked at Fourlog Park. Among these are Agoseris glauca and Taraxacum sp. A few species such as Erythronium grandiflorum and Phleum alpinum were sampled only at Fourlog Park.

While total vegetative coverage is quite similar at all three sites, the average ratios of graminoids to forbs (G:F) differs considerably between the two alpine sites and the subalpine grassland at Fourlog Park. Average G:F ratios at Libby Flats and Lake Marie are 33:77 and 32:78, respectively. At Fourlog Park the average G:F is 49:52, an indication of the grassland nature of the site as opposed to the alpine forb-turf physiognomy of the Libby Flats and Lake Marie sites.

2. Biomass. No information on biomass is available at this time. The core washing machine was not finished until early November, 1972, and the operational techniques are still being developed. Data on both above- and below-ground biomass should be available by early spring, 1973.

3. Phenology. The details of phenology over a two year period will be presented in the Final Report.

The general trend in 1972 was as follows. On Libby Flats most of the forbs were in the vegetative to early bloom stage on 6/12/72. By 7/10/72 the flowering period was terminating for the forbs and by 8/7/72 fall colors were beginning to become evident. Graminoids remained in a vegetative stage somewhat longer than the forbs, but by 8/7 to 8/21/72 they were either producing seed or showed signs of fall coloration.

A similar trend was noted at Lake Marie, with most of the forb taxa in some stage of floral development by early-July and in fall colors by mid-August. The slightly later development of graminoids also occurred at the Lake Marie site.

Fourlog Park was not sampled until early July. At that time both Carex ebenea and Potentilla diversifolia were in full bloom but Stipa comata was still vegetative. By 8/9/72 all three of these major species were at the seed stage. All taxa were generally in fall colors or curing by 8/23/72, except for Lewisia pygmaea which was cured by 7/26/72 and not sampled after that date.

DISCUSSION

The three sites described in this report represent two distinct types of high elevation vegetation. Two of them, Lake Marie and Libby Flats, are definitely alpine in nature. The composition of the flora on these alpine sites, while not exactly alike, is very similar. Yet there are some distinct differences in environment between them. The Lake Marie site, at over 3400 m elevation, was in 1972 the warmer of the two sites. This is somewhat surprising. On the basis of the adiabatic gradient of 1°C loss in average temperature per 100 m gain in elevation, a 2.0 to 2.5°C lower temperature regime would be expected as the Lake Marie site is over 200 m higher than the Libby Flats site.

It is possible the Libby Flats site may experience some nocturnal cold air drainage. However, as it is located near the top of a gentle ridge without higher surrounding terrain, and is apparently quite windy, cold air drainage is unlikely to occur. In fact, the Lake Marie site which is located on concave topography and has higher elevation terrain to the north and east would seem to be the more likely site for cold air drainage to occur. The assumption that the Lake Marie site is the warmer of the two alpine sites during the summer is, of course, based on only one season's data. It will be interesting to see if the phenomenon holds true in subsequent years.

The colder temperatures recorded at Fourlog Park are not as unexpected. Protection from strong wind and higher surrounding terrain would allow cold air drainage to occur. The long-lying snowbanks in the surrounding forest may also be a factor. These areas are protected from direct solar radiation by the tree canopy and should have a very low wind regime as well. Thus, cold air could build up under the forest canopy quite readily and flow into the Fourlog Park site.

The major environmental difference between Fourlog Park and Libby Flats appears to be the wind regime. Winds may be up to five times as strong at Libby Flats. There may be other differences. One on which there is, as yet, no data is the soil moisture status of the two areas. A general impression, established while installing the instrumentation is that the soils at Fourlog Park have a surface water table early in the growing season, but dry out very rapidly. Furthermore, they do not have nearly as much organic matter content in the surface horizons as the soils at either of the alpine sites. Burrowing rodent activity is also much greater in Fourlog Park and there is a considerable amount of exposed

soil in comparison to the alpine sites where most of the ground surface not covered by vascular vegetation or rocks has a cryptogam cover.

Regardless of environmental similarities or differences between Fourlog Park and Libby Flats, the vegetation is distinctly different. Fourlog Park is without doubt representative of sub-alpine grassland. The only surprising element of the vegetation is the relative commonness of Stipa spp. in relation to Deschampsia caespitosa, which is generally considered to be the characteristic species of subalpine grasslands.

Table 1. Mean percentage species coverage and frequency at Fourlog Park, 1972.

Taxa	7/12		7/26		8/9		8/23		Average	
	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.
Carex ebenea	44.2	84	38.9	96	38.2	80	44.2	92	41.4	88
Potentilla diversifolia	32.7	80	21.5	80	22.1	76	18.6	76	23.7	78
Stipa columbiana	14.9	12	13.2	12	19.2	48	14.0	48	15.3	30
Erigeron simplex	12.4	52	15.2	72	12.4	72	11.3	68	12.8	66
Agoseris glauca	17.8	60	11.5	56	6.8	56	2.9	40	9.8	35
Achillea lanulosa	12.1	92	6.2	92	10.7	96	8.9	92	9.5	93
Sibaldia procumbens	11.4	36	11.1	48	4.8	16	5.6	32	8.0	33
Taraxacum sp.	14.6	64	3.8	52	4.0	44	3.1	64	6.4	43
Deschampsia caespitosa	5.4	48	6.6	16	2.8	16	2.1	24	4.2	26
Stipa lettermanni	2.5	4	2.1	44	3.9	24	8.4	28	4.2	26
Poa rupicola	0.6	4	2.2	48	3.7	52	4.3	60	2.7	41
Lewisia pygmaea	10.3	68	0.6	4					2.7	18
Poa cusickii	4.0	60	1.8	32	2.8	52	0.7	28	2.3	43
Aster sp.	1.4	16	0.1	4	1.5	4	1.8	32	1.2	14
Phleum alpinum	1.0	20	0.4	16	0.4	16	1.7	28	0.9	20
Polygonum bistortoides	0.6	24	0.8	12	0.2	8	0.1	4	0.4	12
Draba aurea	1.7	12							0.4	3
Danthonia intermedia							0.8	12	0.2	3
Senecio fremontii			0.7	8	0.1	4			0.2	3
Thlaspi alpestre	0.2	8			0.5	20	0.1	4	0.2	8
Plantago sp.			0.7	8					0.2	2
Gentiana algida					0.6	4			-0.2	1
Trifolium parryi							0.6	4	-0.2	1
Arenaria obtusiloba	0.1	4	0.3	12			0.1	4	-0.2	5
Trisetum spicatum	0.2	8			0.1	4	0.1	4	0.1	4
Antennaria rosea							0.2	8	-0.1	2
Cerastium arvense							0.2	8	-0.1	2
Carex obtusata							0.2	8	-0.1	2
Luzula spicata							0.1	4	-0.1	1
Potentilla sp.							0.1	4	-0.1	1
Erythronium grandiflorium	0.1	12							-0.1	3
Unidentified taxa	0.5								-0.2	
Total forbs	115.8		72.7		63.7		54.1		76.6	
Total graminoids	72.8		65.2		71.7		76.6		71.6	
Total vegetation	188.6		137.9		134.8		130.7		148.2	

Table 2 . Mean percentage species coverage and frequency at Libby Flats, 1972.

Taxa	6/12		6/26		7/10		7/24		8/7		8/21		Average	
	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.
Geum rossii	34.5	100	36.5	100	57.0	100	42.3	100	21.0	92	29.9	88	35.2	96
Selaginella densa	26.6	52	21.0	52	14.8	56	22.5	60	21.9	64	15.3	60	20.4	57
Artemisia scopulorum	14.9	96	16.2	88	26.2	96	21.0	88	11.3	80	19.3	80	18.2	88
Trifolium parryi	7.4	80	16.0	84	22.8	96	22.5	80	8.7	76	13.5	80	15.2	83
Deschampsia caespitosa	6.7	56	14.3	36	21.1	68	14.0	64	8.5	40	24.3	68	14.8	55
Polygonum bistortoides	7.9	100	14.3	100	16.5	96	9.3	92	2.6	44	2.5	72	8.9	84
Agrostis idahoensis	0.3	12	4.5	64	7.7	68	9.5	68	1.5	40	4.3	76	3.9	55
Potentilla diversifolia	2.5	60	7.6	48	2.5	36	3.8	44	2.0	60	1.0	40	3.2	48
Achillea lanulosa	2.0	60	2.7	68	1.1	44	4.5	64	2.7	68	4.9	60	3.0	61
Carex ebenea	4.4	60	0.7	8	1.3	12	5.7	20	0.2	8	7.8	44	2.5	25
Carex albo-nigra			2.0	20	1.8	12	5.7	20	0.7	8	2.5	4	2.1	11
Erigeron simplex	0.4	16	3.5	40	1.7	28	5.0	24	0.7	28	0.7	8	2.0	24
Poa rupicola	6.4	44	1.9	0.6	0.6	24	2.0	40			0.5	20	1.9	24
Arenaria obtusiloba			3.5	40	1.2	24	1.5	20	2.8	16	2.2	32	1.8	22
Carex obtusata	0.6	4	2.2	28	2.8	16	1.9	16	0.9	36	1.0	20	1.6	20
Festuca ovina			1.2	8			0.6	4	1.7	28	5.7	52	1.5	15
Poa alpina	3.3	32	1.2	28	1.5	20	0.3	12	0.9	36	0.6	16	1.4	24
Saxifraga rhombidea	4.2	56	2.3	52	0.6	24							1.2	22
Carex rossii			3.4	4	0.8	12	2.5	24			0.3	12	1.2	9
Pedicularis parryi	0.7	12			0.8	12	2.0	20	1.3	12			0.8	9
Polemonium viscossissium	1.9	36	0.7	8	0.2	8	1.8	32	0.1	4			0.8	15
Luzula spicata			1.6	24	1.9	36	0.7	28	0.3	12	0.1	4	0.8	17
Sedum stenopetalum	0.5	20	2.1	24	0.7	8	0.7	8			0.2	8	0.7	11

Table 2 (Cont.). Mean percentage species coverage and frequency at Libby Flats, 1972.

Taxa	6/12		6/26		7/10		7/24		8/7		8/21		Average	
	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.
Cerastium arvense	0.3	12	0.1	4	0.9	36	1.0	40	0.2	8	1.4	68	0.7	28
Danthonia intermedia									1.5	20	2.5	20	0.7	7
Thlaspi alpestre	0.9	36	0.7	28	0.5	20					0.5	20	0.4	17
Mertensia alpina	1.3	12	0.7	8	0.3	12					0.2	8	0.4	7
Senecio fremontii							1.1	24	1.4	16			0.4	7
Solidago sp.											2.2	12	0.4	2
Koelaria cristata	0.8	12	0.3	12	0.3	12			0.7	8	0.3	12	0.4	9
Aster apligenus			0.1	4	2.0	20							0.4	4
Agoseris glauca	0.2	8	0.1	4	0.3	12	0.3	12	0.9	16			0.3	9
Silene acaulis	1.4	16	0.1	4									0.3	3
Lewisia pygmaea			0.8	12	0.5	20							0.2	5
Antennaria rosea	0.3	12	0.2	8	0.2	8	0.1	4			0.2	8	0.2	7
Trisetum spicatum					0.1	4	0.7	8	0.2	8			0.2	3
Draba aurea	0.2	8	0.6	24							0.2	8	0.1	5
Gentiana algida					0.6	4	0.1	4					0.1	1
Pedicularis groenlandica											0.7	8	0.1	1
Agropyron scribneri											0.7	4	0.1	1
Taraxacum sp.			0.6	4							0.1	4	0.1	1
Potentilla sp.	0.3	12											-0.1	2
Phlox multiflora	0.1	4											-0.1	1
Trifolium nanum			0.1	4									-0.1	1
Festuca rubra											0.1	4	-0.1	1
Total forbs	81.8		130.5		151.4		139.5		77.6		95.0		112.6	
Total graminoids	22.5		33.3		39.9		43.6		17.1		51.0		34.6	
Total vegetation	104.3		163.8		191.3		183.1		94.7		146.0		147.2	

Table 3. Mean percentage species coverage and frequency at Lake Marie, 1972.

Taxa	6/27		7/11		7/25		8/8		8/22		Average	
	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.	Cov.	Freq.
Geum rossii	35.9	100	35.6	100	51.2	100	36.9	100	59.0	100	43.7	100
Artemisia scopulorum	12.7	100	17.8	100	19.2	92	18.1	84	25.7	92	18.7	94
Selaginella densa	21.3	56	23.1	52	10.7	32	18.4	48	18.2	56	18.3	49
Deschampsia caespitosa	11.5	60	25.0	100	15.4	84	16.3	76	15.6	72	16.8	78
Carex albo-nigra	5.2	20	8.4	28	16.4	44	3.7	4	3.3	16	7.4	22
Sibaldia procumbens	3.9	20	10.5	20	3.9	20	11.9	20	5.7	20	7.2	20
Agrostis idahoensis	2.9	76	2.4	56	2.2	68	0.9	36	18.8	72	5.4	62
Erigeron simplex	5.2	72	6.5	64	6.8	76	3.4	76	4.5	80	5.3	74
Polygonum bistortoides	6.5	84	5.9	76	5.8	92	2.2	68	3.1	64	4.7	77
Trifolium parryi	2.3	32	2.7	28	7.9	32	1.8	24	1.1	24	3.2	30
Potentilla diversifolia	2.5	40	2.0	40	2.5	60	1.5	60	2.7	52	2.2	50
Gentiana algida			4.8	36	1.1	24	4.1	44	1.2	28	2.2	26
Arenaria obtusiloba	1.7	28	1.1	24	0.7	28	1.1	24	2.0	40	1.3	29
Carex ebenea	0.3	12	0.1	4			0.1	16	4.9	24	1.1	11
Pedicularis parryi					4.3	20	0.1	4	0.1	4	0.9	5
Pedicularis groenlandica	1.2	28	1.4	16	0.2	8	0.3	12	0.5	20	0.7	17
Carex rossii	2.7	28			0.9	16					0.7	9
Erigeron compositus	1.2	28	1.8	12	0.1	4	0.1	4			0.6	10
Saxifraga rhomboidea	1.9	56	0.7	28							0.5	17
Thlaspi alpestre	1.6	24			0.2	8	0.1	4	0.3	12	0.4	10
Luzula spicata			0.4	16	1.1	24	0.1	4	0.4	16	0.4	12
Carex obtusata	0.2	8	0.1	4	0.1	4	0.5	20	0.8	12	0.3	10
Trisetum spicatum	0.2	8	0.3	12	0.2	8	0.5	20	0.4	16	0.3	13
Festuca ovina							0.9	36			0.2	7
Silene acaulis	0.1	4	0.6	4	0.1	4					0.2	2
Poa alpina	0.1	4					0.6	4			0.2	2
Lewisia pygmaea			0.5	20	0.2	8					0.2	6
Achillea lanulosa							0.6	4			0.1	1
Cerastium arvense			0.1	4	0.1	4			0.3	12	0.1	4
Agoseris glauca	0.1	4							0.2	8	-0.1	2
Trifolium nanum					0.2	8					-0.1	1
Danthonia intermedia							0.2	8			-0.1	1
Sedum stenopetalum					0.1	4					-0.1	1
Koelaria cristata	0.1	4									-0.1	1
Total forbs	98.1		115.1		115.3		114.2		124.6		113.5	
Total graminoids	23.2		36.7		36.3		23.7		44.2		32.8	
Total vegetation	121.3		151.8		151.6		137.9		168.8		146.3	

The Effect of Certain Environmental Factors (Including Snow Cover) on Forest Understory Species Composition (Rogers and Knight)

The Effect of Certain Environmental Factors (Including Snow Cover) on a Meadow Complex in Headquarters Park (Starr and Knight)

In order to predict the potential effect of increased snow fall on vegetation, it is necessary to have information on the factors that most limit the abundance of the major species. These two studies will provide some of that information. A gradient analysis approach will be used for both, with data from 30 to 40 stands being obtained for each. The stands have been selected to include a range of environmental conditions, particularly with regard to soil structure, soil chemistry, snow duration, air and soil temperature, and light availability (in the forest stands). Vegetation data are being collected in terms of species phenology and species cover.

These studies were initiated in 1972, with most of the effort going to stand selection, species identification, and decisions on methodology. The forest stands are located in the Brush Creek and French Creek watersheds, and the meadow stands in Headquarters Park, which has an interesting and diverse group of communities. Data analysis cannot begin until all stands have been sampled and that will not be accomplished until the end of next summer. Thus, no results on limiting factors can be reported at this time. One set of data was gathered from a lodgepole stand, however, and it may be of interest.

We observed that lodgepole stands above 9500 feet occasionally had a very patchy understory vegetation. The patches are now believed to be associated with different snowmelt patterns (see section on Vaccinium scoparium), but that remains to be proven in this first stand that was sampled. The presence or absence of Vaccinium scoparium was the most conspicuous cause of the patchiness. Forty quadrats (each 1 m^2) were sampled for species density in patches dominated by V. scoparium and 40 were sampled in patches where V. scoparium was rare or absent. These first results can be summarized as follows:

1. Only one species, Abies lasiocarpa seedlings, seemed to occur with V. scoparium more often than would be expected by chance. Could the huckleberry be providing a special microenvironment favorable to fir regeneration?
2. Four species were found in about equal abundance within the two patch phases, Erythronium grandiflorum, Carex geyeri, Hieracium gracilis, and the seedlings of Picea engelmannii.
3. Eleven species seemed to be negatively associated with V. scoparium more often than would be expected by chance, Arnica cordifolia, Senecio sp., Claytonia lanceolata, Carex sp., Poa sp., Lewisia pygmaea, Antennaria sp., Epilobium sp., Sibbaldia procumbens, and two still unidentified grasses. These species could possibly become more common if V. scoparium became less abundant.

The species named by genus only will be identified next summer, and a statistical analysis of these data has yet to be done. Thus, the associations identified above are only tentative. No comparable data have yet been obtained from the meadows of Headquarters Park.

Another set of data was collected during the summer of 1972, and though very little money from the Medicine Bow Project was expended on this work, the results are of considerable value to the Project. The data are of a phytosociological nature, obtained from 40 stands of lodgepole pine forest, and were collected by Mr. Irwin Patterson. A summary of his data is not feasible at this time, but his results have furthered our understanding of the lodgepole forest ecosystem in the Medicine Bow Mountains and will be incorporated into the final analysis of the forest sub-project described above.

The Autecology of *Vaccinium scoparium* Leiberg

(Kyte and Knight)

Vaccinium scoparium, commonly called huckleberry or grouse whortleberry, is a small shrub that appears to be by far the most common plant in the understory of most lodgepole pine forests and spruce-fir forests in the Medicine Bow Mountains. Where huckleberry occurs, it forms a carpet of green on the forest floor. Because of this, and because we now know it is sensitive to snow duration, we have initiated this sub-project to learn as much as possible in the time available about the ecological characteristics of *V. scoparium*. Only with this information can we confidently predict 1) the effect of snow duration on the forest understory, and 2) what the ecological significance of this effect might be to the forest as a whole. For example, we are planning to determine if *V. scoparium* is a nitrogen-fixer. Other members of the Ericaceae are known to play this role in some ecosystems. If *V. scoparium* is reduced in abundance by winter precipitation management, will the forest N budget be modified sufficiently to affect tree growth? We are now beginning to work toward the answer of this question and others.

During the 1972 summer, a concerted effort was initiated to determine if persisting snow could modify the environment sufficiently to prevent the survival of *V. scoparium*. This was done by observing periodically the snow persistance at several elevations ranging from about 9,200 ft. to 10,200 ft. Stakes were driven into the ground around the edge of specific banks, which were then visited periodically in order to determine the rate of snow melt and growth status of *V. scoparium* on specific dates.

Two specific questions were of interest in 1972:

1. How long must snow persist before V. scoparium does not occur on a site?
2. What is the time period between complete snow melt around a plant and bud burst, and how long from no snow to apparent complete elongation and foliation?

The above questions were considered on the following study areas in 1972. These same areas, and others, will be observed again in 1973.

1. Libby Creek Lodgepole Stand, on left side of Barbara Lake Road at parking area just above the turn-off to Medicine Bow Ski Area, on eastern slope at about 9,450 ft.
2. Ned's Ridge, approximately 2 miles west of the Libby Creek Stand on the Barbara Lake Road, another lodgepole forest on the east slope at about 9,500 ft.
3. West slope lodgepole stand, on north side of Hiway 130 at about 9,500 ft.
4. Upper French Creek lodgepole stand, on north side of Hiway 130 at about 9,600 ft.
5. Headquarters Park spruce-fir stand #1 at about 10,200 ft. near the dry meadow experimental area.
6. Headquarters Park spruce-fir stand #2, at about 10,000 ft. near the wet meadow experimental area.

Preliminary Results

First, some observations on the phenology of snow melt may be of interest. By June 1, 1972, complete snow cover did not exist at about 9,500 ft.; only scattered snow banks persisted, ranging in size from about 50 to 150 ft.^{2} and 1 to 3 ft. deep. Most banks at this elevation

had completely disappeared by about June 10-20 (depending on slope and canopy cover). At 10,000 ft. (Headquarters Park) large snow banks still persisted on July 3, 1972. Most of these banks were gone by July 15. Generally, snow persisted later in the forest than in the adjacent meadows of Headquarters Park.

Based on observations in Stands 1, 2, and 3 at about 9,500 ft., the persistance of snow until June 10-20 has no detrimental effect on the survival of V. scoparium. At 9,600 ft. (Stand 4), the shrub may have been slightly less abundant and slightly less vigorous where snow banks persisted until late June, but the effect was not clear. V. scoparium was almost completely absent from areas where snow persisted beyond about July 3, based on observations in Stands 5 and 6. In fact, the shape of the patches that resulted due to the absence of huckleberry was almost exactly the shape of the snow banks on July 3. In sum, it appears that if snow persists beyond about late June or the first of July, the survival of V. scoparium may not be possible. In experiments that are described later, we will determine if V. scoparium can be killed on small plots by keeping plants snow-covered until July 1. The fungus Pucciniastrum goeppertianum (Kuehn) Kleb. appears to be detrimental to huckleberry and we will watch to see if it becomes more abundant on those plants subject to longer snow cover.

With regard to plant development, our first set of observations indicate the period between snow melt and bud burst is about 14 days, and about 24 days between snow melt and complete elongation and foliation. These numbers are not, however, based on sufficient observations; more measurements will be made during the next growing season. An attempt will also be made to measure the photosynthetic contribution of the chlorophyll-containing stems of V. scoparium, in order to determine their adaptive significance.

The Effect of a Snow Treatment on Subalpine Meadow and Forest Understory Vegetation - Knight and Kyte

In the most general sense, the snow treatment to the Medicine Bow Mountains is planned to begin with cloud seeding in 2 - 3 years. The research summarized in this section and throughout this report is designed to evaluate the effect of that pilot experiment. However, as discussed earlier that treatment will be difficult to evaluate due to lack of control. Therefore, a series of small-scale experiments have been initiated in which the snow treatment is applied by shovel rather than cloud seeding. The experiment will be continued for three or more years and is being conducted on the following sites, each of which is about one acre in size:

1. A dry meadow in Headquarters Park, 10,200 ft.
2. A wet meadow in Headquarters Park, 10,100 ft.
3. A mesic meadow near the Soil Conservation Service monitoring installation, near Headquarters Park at 10,000 ft.
4. Spruce-fir forest understory dominated by Vaccinium scoparium near Headquarters Park at about 10,200 ft.
5. Lodgepole pine forest understory dominated by Vaccinium scoparium near Hiway 130 at about 9,800 ft.

The experiment has been set up at each of the 5 sites using a randomized complete block design, with 5 control plots and 5 treatment plots. Each plot is approximately 1.5 m^2, and the plots were paired into blocks according to their apparent similarity. In the spring, snow will

be piled onto the treatment plots in order to maintain snow cover for approximately 14 days longer than on the control plots. This snow treatment will be done each spring for 3 growing seasons, with plant phenology and growth being monitored each year. Analysis of variance will be used to test the null hypothesis of no difference; more replications will be added if initial data analysis suggests the need.

Methods

The effect of winter precipitation management, if there is one, will be indirect through modification of the plant environment. The following changes are possible and will be measured on the experimental plots as described below:

1. Shortened growing season. Though this is apparently debateable, we have observed snow drifts whose disappearance varies considerably from one year to the next. Snow drifting is an important phenomenon in the Medicine Bow Mountains, and cloud seeding could increase the size of drifts not already filled to capacity. Therefore, a growing season shortened by 2 weeks seems a reasonable possibility. If effects can be observed with a 2 week delay, then shorter delays will be examined in subsequent experiments. These data on length of growing season are easily obtained by frequent visits to the sites.
2. Modification of soil and air temperature in the plant microenvironment. The snow treatment will cause a lag in soil and air warm-up; plants beginning growth 2 to 4 weeks later do so in a different environmental regime. Soil temperature will be measured in each plot with a

max-min thermometer located in the plant canopy. A hygrothermograph is also located on each of the 5 sites at ground level during the growing season.

3. Soil water will not be increased by additional snow if the soil is already saturated, but if the snow persists for a longer time the soil water will be available when air temperatures and solar radiation are higher. Therefore, soil water potential will be measured with thermocouple psychrometers at 2 depths and radiation is being measured with a pyranograph. Soil drying rates will be measured following snow melt.

Plant phenology and growth rate will be measured on each plot with non-destructive methods appropriate for each species.

Biomass. Each of the 3 meadow sites was sampled for biomass in 1972 using 8 to 12 objectively located quadrats, each $1m^2$. The above-ground material was clipped at the soil surface, separated by species, dried in an oven, and weighed. This was done once on the Dry Meadow at the time of estimated maximum biomass, and twice on the Wet and Mesic Meadows. The clipped quadrats were in the same stands but at least 3 meters from the experimental plots. The biomass data will be used to estimate productivity of the major species. Root cores were taken from the meadows in order to estimate root biomass, but they have not yet been washed free of soil. They are being stored in a frozen condition. Biomass was not estimated in the forest understory, primarily because of the difficulty in accurately estimating productivity of woody species such as Vaccinium scoparium with the harvest method.

Biomass and productivity on the experimental plots will not be estimated until after three years of snow treatment, at which time the

plots will be harvested and the data analyzed statistically to test the null hypothesis. In addition to analysis of variance, regression analysis may be used to determine the degree to which growing season length, soil water potential, soil and air temperature, and vapor pressure deficit are correlated with plant phenology and productivity.

Preliminary Results

Results from the small-scale experiment are not yet available since the first snow treatment will be applied next June. Reported in this section are the first results on species biomass in the meadows and a brief summary of the environment at each of the 5 study areas. The environmental data have not yet been summarized completely.

Biomass Data. The Dry Meadow at Headquarters Park had a total biomass of about 10 g/m^2 on July 26, 1972. This meadow is believed to have been at about maximum biomass at this time; three samples will be taken in 1973, including one again on July 26. After cloud seeding begins, this meadow will be sampled for biomass on July 26 for several years in an attempt to detect changes greater than might be expected under normal conditions.

With regard to species composition of the Dry Meadow, Sibbaldia procumbens, Viola adunca, Carex haydeniana, and Agrostis humilis are most abundant and comprise two-thirds of the total biomass (Table 4). Erythronium grandiflorum and Claytonea lanceolata are common earlier, but have decomposed by mid-July. Sibbaldia procumbens comprised 38% of the total biomass in 1972, and since this species is considered to be well adapted to snow accumulation areas, the Dry Meadow may be quite tolerant of increased snowfall. Erythronium grandiflorum is also thought to be well adapted to snow accumulation.

An attempt will be made to determine what proportion of the meadows in the Medicine Bow Mountains are similar to the Dry Meadow study area.

The Wet Meadow at Headquarters Park is very different, having water on the soil surface late into the growing season. At the end of July (7/31/72) the average biomass per m^2 was 143 g, fourteen times the biomass on the Dry Meadow. Species separation was extremely slow and only one sample could be obtained in 1972. A still unknown Carex is the most abundant species, followed by Deschampsia caespitosa and Caltha leptosepala (Table 5). Other common species included Juncus drummondii, Pheum alpinum, Ranunculus alismaefolius, and Trisetum woolfii.

The SCS Meadow is mesic and appears quite different from the other two meadows, though the total above-ground biomass is about the same as on the Wet Meadow. Biomass was measured in mid-July and mid-August, with no great difference in total biomass but a large shift in the contribution of several species. A still unidentified Carex and Deschampsia caespitosa were dominant at both times, but much more so in August (Table 6). Other less abundant species with this same trend are Erigeron peregrinus and Agoseris glauca. A larger number of species declined in biomass between mid-July and mid-August, in particular Ranunculus alismaefolius, Polygonum bistortoides, and Senecio dimorphophyllus. Plantago tweedii was about equally abundant both times.

This first year's set of biomass data is not as complete as we would have liked in order to calculate net community productivity. There were problems with species identification and separation of biomass by species was very slow. Most of the identification problems have now been solved, and the work should progress more rapidly next summer, permitting a reasonable estimate of productivity. Though the data have

not been tested yet for sample adequacy, the species proportions are probably sufficiently close to provide a basis for evaluating the effect, if any, of precipitation management on species composition in the 5 study areas.

Environmental Data. The environmental data from the 5 study areas have not been completely summarized, but a few observations can be made. The three meadows all received about 13 cm of precipitation between July 5 and September 22, 1972, with most of the rainfall occurring in August. The forest stand measurements were about 2.5 cm less, but canopy interception could account for this difference.

Freezing temperature was recorded at each site during June, July, and August, with the exception of the two forest stands in July. The lodgepole stand was the warmest, being at a lower elevation than the others. The SCS Meadow had the highest daily mean temperature, but the lowest nightly mean temperature; cold air drainage probably occurs through this area. The Wet Meadow was the coolest in terms of daily mean temperature. Maximum daytime temperatures at all study areas were 18 to 21° C, measured about 20 cm above the soil surface.

Relative humidity ranged from about 45-50% during the day to 75-80% at night. Vapor pressure deficit has not yet been calculated, but the lodgepole forest stand and the dry meadow have the lowest average relative humidity.

Difficulty was encountered with the calibration of the thermocouple psychrometers, but this will be done in time for installaltion immediately after snow melt. No soil moisture or soil temperature data are yet available, though the frozen root cores will be sampled for soil moisture as well as root biomass.

TABLE 4

BIOMASS DATA (g/m^2) FOR THE DRY MEADOW AT HEADQUARTERS PARK

ON

JULY 26, 1972.

Species	g/m^2
Achillea lanulosa	0.205
Agrostis humilis	0.629
Arenaria sajinensis	0.506
Carex haydeniana	0.785
Draba stenoloba	0.008
Erigeron?	0.133
Juncus drummondii	0.305
Lewisia pygmaea	0.133
Luzula spicata	0.093
Phleum alpinum	0.122
Plantago tweedii	0.209
Poa epilis	0.063
Poa?	0.418
Polygonum bistortoides	0.084
Potentilla diversifolia	0.070
Selaginella sp.	0.441
Sibbaldia procumbens	3.712
Stellaria borealis	0.051
Thlaspi alpestri	0.008
Veronica wormskjoldii	0.009
Viola adunca	1.270
Moss	0.489
Veronica (gentian)?	0.012
Viola-like unknown	0.011
Average g/m^2	9.7

TABLE 5

BIOMASS DATA (g/m^2) FROM THE WET MEADOW AT HEADQUARTERS PARK

ON

JULY 31, 1972.

Species	g/m^2
Agrostis humilis	1.13
Arnica mollis	3.34
Caltha leptosepala	16.94*
Carex aquatilis	0.63
Carex #1	43.44*
Deschampsia caespitosa	26.09*
Epilobium halleanum	1.06
Erigeron peregrinus	3.47
Juncus drummondii	5.16
Juncus mertensianus	0.06
Pedicularis groenlandica	0.69
Phleum alpinum	5.53
Poa reflexa	1.22
Polygonum bistortoides	0.13
Potentilla diversifolia	0.06
Ranunculus alismaefolius	7.19
Sedum rhodanthum	0.09
Senecio dimorphophyllus	1.44
Stellaria borealis	0.16
Trisetum woolfii	6.16
Trollius laxus	0.03
Veronica wormskjoldii	0.41
Unknown Moss #1	14.34
Unknown Juncus #2 (probably not Juncus)	3.78
Unknown Gentian	0.03
Average g/m^2	142.58

TABLE 6

BIOMASS DATA (g/m^2) FROM THE SCS MEADOW

ON

JULY 18 AND AUGUST 15, 1972.

Species	July 18	August 15
Achillea millefolium	1.25	0.59
Agoseris glauca	1.25	2.19
Agropyron latiglume		2.03
Agrostis humilis		0.03
Antennaria sp.	0.01	0.44
Carex #1	22.05*	53.38*
Carex #2	1.78	0.59
Carex #3	0.10	
Claytonia lanceolata	0.53	
Deschampsia caespitosa	9.04*	34.41*
Draba stenoloba	0.30	0.22
Epilobium halleanum	1.43	0.69
Erigeron #2	0.88	0.19
Erigeron #3 ?		0.09
Erigeron peregrinus	4.83	14.25*
Erythronium grandiflorum	0.03	
Hordeum brachyantherum		1.75
Juncus drummondii	5.55	0.38
Lewisia pygmaea	0.28	
Phleum alpinum	5.58	5.19
Plantago tweedii	21.95*	15.84*
Poa annua	0.44	0.16
Poa epilis	0.27	0.03
Poa interior	0.02	
Poa leptocoma	0.52	0.13
Poa reflexa	6.75*	4.44
Polygonum bistortoides	7.88*	3.94
Potentilla diversifolia	2.65	4.06
Ranunculus alismaefolius	32.30*	
Rorippa sinuata	0.25	2.50
Senecio dimorphophyllus	5.95	1.75
Sibbaldia procumbens	0.48	0.19
Spergularia rubia	0.13	0.06
Stellaria borealis	0.05	0.13
Taraxacum officinale	2.33	0.53
Thlaspi alpestre	0.20	
Trisetum spicatum	0.70	0.13
Veronica #2	0.10	
Veronica wormskjoldii	1.45	1.28
Viola adunca	0.03	0.03
Unknown grass 6	0.02	
Unknown grass 3	1.17	
Unknown grass 10	1.17	
Average g/m^2	141.70	151.62

THE IMPACT OF SNOW ON ELK

Ward, Strickland, Diem, and Weeks

Late fall, winter and early spring seasons represent very stressful times for elk in the Central and Northern Rocky Mountains. A variety of natural and man-induced factors may singly or in combination bring about significant changes in the movement, distribution and general welfare of the animals. Snow accumulation is one of these important stress factors. If changes do occur in elk populations, the type and degree of that change can be determined through comparison to some established frame of reference. For these reasons this study has had the following objectives:

1. Development of pre-cloud-seeding baseline inventory data, i. e., population numbers, composition, movement and distribution on their seasonal ranges.
2. Identification, description, and where possible, measurement of the various factors (with special emphasis on snow) which influence the movement, distribution and general welfare of elk.

The proposed target area specifically affected by cloud seeding on the Medicine Bow Range is extensive. It was necessary that a smaller area be selected for intensive pre- and post-seeding evaluation. The area from French Creek south to the Colorado-Wyoming state line is being used. Within this area 701 elk were counted from the air on February 26, 1971.

There is very little specific information in the literature on the response of elk to snow accumulation. Gaffney (1941) stated that the

amount of snow in which elk can winter successfully depends on several factors: 1) the composition, height, and volume of the palatable vegetation; 2) condition of snow -- packed, crusted, or loose; 3) age and condition of the animals; and 4) topography and weather conditions. He found on the south fork of the Flat-head River, Montana, that elk often nosed through 12 to 18 inches of loose snow while feeding on bunchgrass and frequently pawed to obtain food in 36 inches of moderately loose snow. He concluded that, generally, 48 inches of snow represents the maximum in which the elk can range efficiently and that they will buck 12 to 18 inches more snow on the flats than on a hillside. Anderson (1954) studied migration of elk in Jackson Hole. He states that snow depths of 6 to 10 inches started mass migration out of Yellowstone Park.

Contact was made with Dr. Harold Steinhoff who is studying elk distribution on the San Juan Forest in relation to show depths and physical characteristics. The San Juan area presents a different situation with respect to snow accumulation and elk distributions, one of the major differences being the relative lack of wind in the San Juan area. Wind can change physical characteristics and distribution of snow, the chill factor, and food availability.

Methods

Telemetry is being used to monitor movement of several cow elk. The use of telemetry has been found to be very valuable, not only in helping to locate the instrumented elk, but also, since elk are gregarious, the groups with which the individuals associate. Both ground tracking and aerial tracking are used. Tracking from the air has been found to be much faster and easier during the summer and fall periods, when the elk

are widely dispersed and in areas of heavy lodgepole pine cover and rough terrain. Individually-numbered neck collars are also being used on some elk in an effort to collect additional elk association and distribution data.

Time-lapse photography systems utilizing Super-8 mm movie cameras and 35 mm time-lapse cameras are being used to monitor elk use of specific feeding sites on winter and summer ranges. Within the camera view there are at least 60 circular plots, 1/100 acre in size, where pellet counts are being made. Vegetation is also being measured within the camera view, using the canopy-coverage method described by Daubenmire (1959). Snow depths on winter sites are monitored by placing color-marked stakes within camera view. Physical characteristics are measured periodically by on-site examinations.

As collaborators in the Earth Resources Satellite project with NASA, remote sensing data from both the satellite and periodic low-level fixed wing aircraft are being analyzed. Satellite coverage over the study site began on August 2 and is continuing on a regular 18 day cycle. Cloud cover over part of the site has created some problems, but very good low-level coverage was obtained over the elk summer range on September 10, 1971 and over all of the seasonal elk ranges on September 9-10, 1972. A well equipped laboratory has been established on campus under the NASA project for analysis of these ERTS data.

Observations and telemetry tracking

An elk trap was erected in the western foothills during February 1972 and baited with grass hay. Twenty elk were trapped in March (17 cows, 3 calves), and seven cows were marked with telemetered collars. In

addition ten cows and three calves were marked with numbered, blaze-colored collars. The transmitters weighed about 2¼ pounds each, and were set to six different frequencies. The two transmitters on the same frequency had different pulse rates so they could be identified. There was 3 to 8 inches of fresh snow on the ground each time elk were caught.

Table 7 is a summary of trips made to the study area, either on the ground or by airplane, to locate and count elk. Only four flights were needed during the period of March through May, since the elk were in the lower country where telemetry signals could be fixed from high ridges (Fig. 1). As the elk moved to the higher country in June they spread out over a large area that is heavily forested with lodgepole pine and cut by many drainages (Fig. 2).

From June to October there were 22 aerial flights made at about weekly intervals as well as several vehicle trips on the ground. All except two of the flights were made within the two-hour period of dawn, thereby providing a chance to locate the maximum number of elk on their feeding sites. There was considerable variation in numbers of elk seen on different flights. The most elk were seen in February on the open ridges of the winter range and in July when they were using the high sub-alpine parks and meadows.

The travels of the telemetered cows are shown in Figure 3. Cow 2 and cow 5 were collared on the same day but spent the summer at the two opposite extremes of the summer range, about 12 to 14 air-miles apart. It is apparent that elk from one trap site on the winter range are well distributed over the entire Medicine Bow Range, from Highway 130 on the north to Douglas and Lake Creeks on the south. Cows 1 and 2, and their

Table 1. Elk location records from March to October, 1972

Time period	Elk ident.	Date transmitter off	Total trips		Times fixed, not seen	Times fixed and seen	Total elk	Classified elk			
			Air	Ground				Cows	Calves	Spikes	Bulls
March 2 to May 31	Cow 1		4	27	16	6	113	42	11	2	
	Cow 2		4	27	11	4	22	5	3		
	Cow 3		4	17	13	5	32				
	Cow 4	May 23	4	24	19	7	67	10	3	9	
	Cow 5		4	22	16	3	11	3	2	1	
	Cow 6		4	18	16	3	52				
	Cow 7		4	17	15	4	35				
	Blaze collars		4	27		7	344	41	22	14	7
Sub-totals					106	39	676	101	41	26	7
June 1 to Oct 31	Cow 1	Aug. 16	11	11	9	5	272	102	58	4	2
	Cow 2		22	23	10	13	191	65	25	2	7
	Cow 3		22	23	17	10	101	19	8		
	Cow 5	July 19	8	6	6	3	37	7	1		
	Cow 6	Oct. 15	19	24	16	4	104				
	Cow 7	Sept. 30	17	22	11	8	166				
	Blaze collars		22	23		7	311	138	81	13	2
Sub-totals					89	72	1,754	354	180	21	17
TOTALS - March to October			26	50	175	111	2,430	453	221	47	24

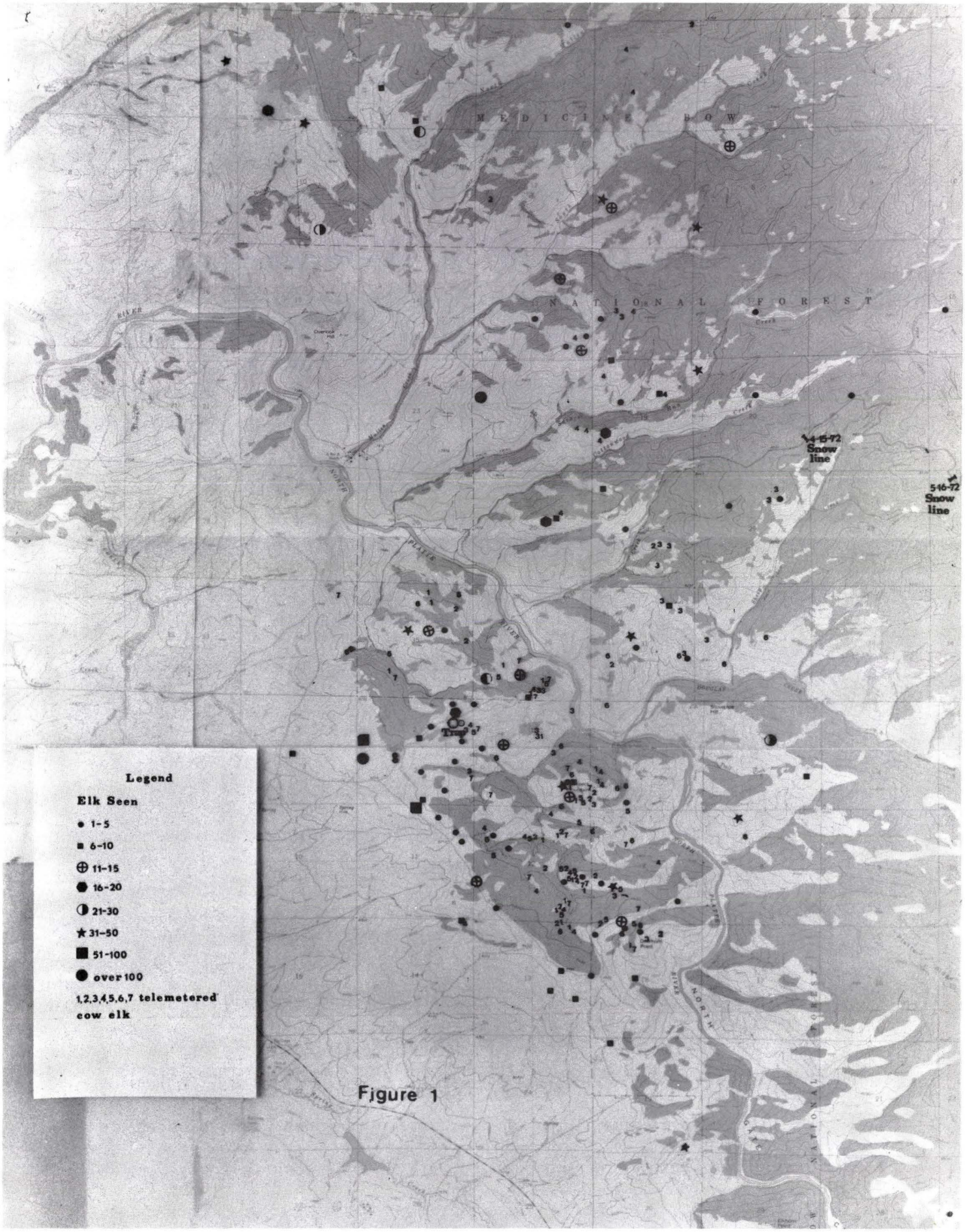


Figure 1 (Elk Report). Elk distribution near trap.

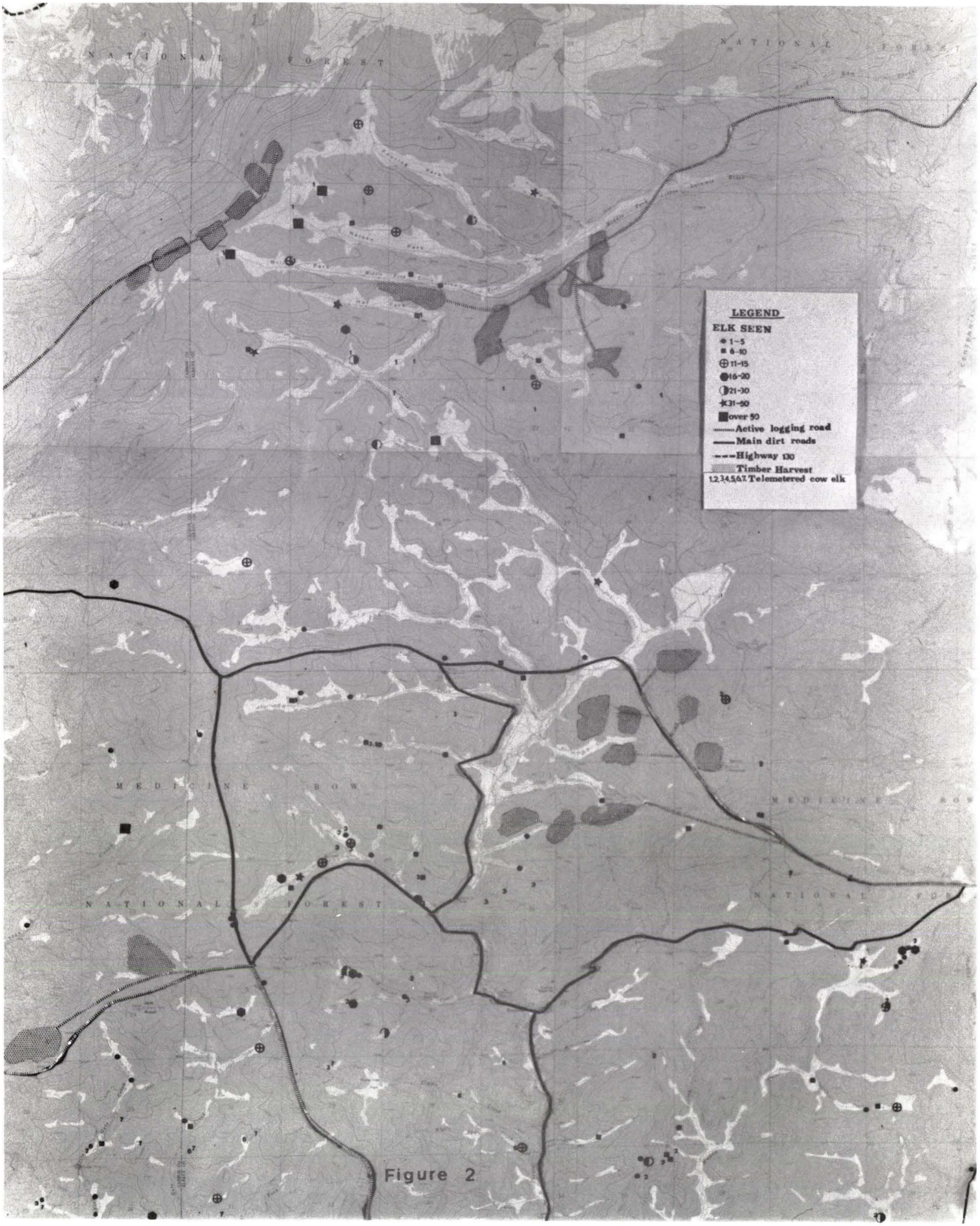
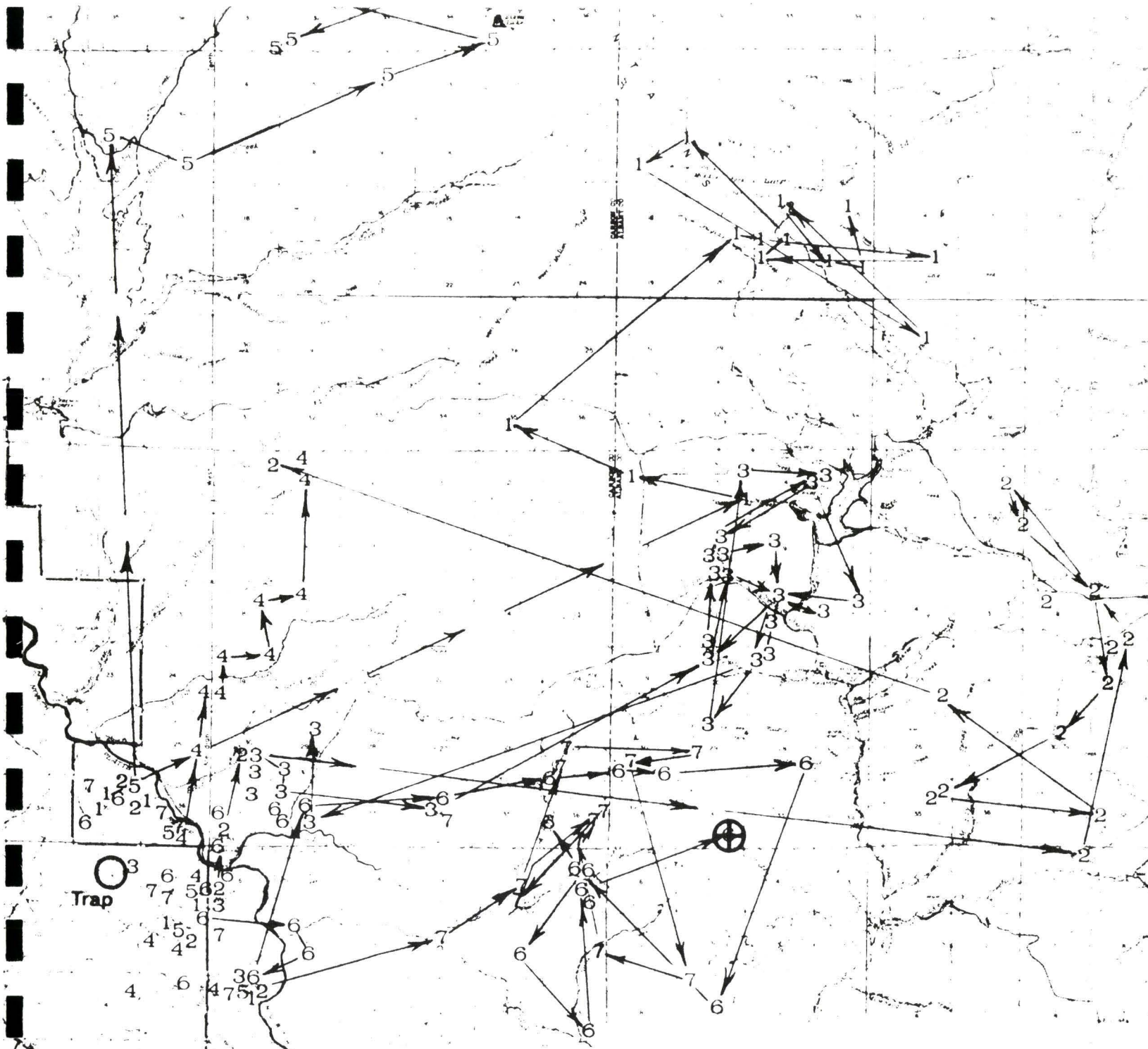


Figure 2 (Elk Report). Elk distribution during the summer, 1972.



Travels of telemetered cow elk

Legend

⊕ Number 6 killed

○ Trap site

→ Elk movement

FIGURE 3

associates, were seen on the east slope of the range during the summer.

During the March-to-October period, 2,430 elk observations were made (many of the same elk were seen several times). There were 747 elk seen well enough for classification, and they consisted of 61 percent cows, 30 percent calves, 6 percent spikes, and 3 percent larger bulls.

The elk marked with numbered collars were seen only 14 times, and only on three occasions was it possible to read the numbers. Based on the limited data received from these animals, it was concluded that this method is very poor if only a few elk can be marked in a large population.

It was not determined if all telemetered cows had calves. Those still in question are cow 1 and cow 5. Cow 2 was judged to be going on two years of age when trapped; the others were larger, older cows.

The telemetered elk were seen alone only on three occasions. Cow 1 was seen with 51 adult cows, 20 calves and 3 small bulls on July 12 in Nelson Park. This herd of 84 elk was the largest seen during the summer. The average number of elk seen with a telemetered cow during the March-to-October period was 17.

Snow relations

Snow cover on the elk winter ranges was very light below 8500 feet elevation where the elk stayed until the middle of May. Nearly all south- and west-facing slopes were open except for one or two days after each storm. There was never a hard crust on the snow on elk feeding sites. The heavy snow cover of about 24 inches started at the 8800 foot elevation; on April 16 the snow was dense enough to drive over in an automobile.

All telemetered elk stayed within a six-square-mile area, within two miles of the trap, until mid-April (Fig. 1). During the latter part of April and May all but one telemetered cow crossed the North Platte River to the east. The last cow (Number 7) finally moved across the river between June 7 and 9. All but the last cow crossed the river before the spring runoff. The last cow with her calf crossed the North Platte River and Douglas Creek during high water.

On May 26, all elk except telemetered cow 1 and two associates were located at least one mile below the snow line (approximately 9400 feet). Cow 1 was located above the snow line at 9600 feet elevation where snow depth was estimated at 8 to 10 inches deep. By May 31, cow 1 had moved back down to the west along Cottonwood Creek where snow depths were much less and where the vegetation was green. This was the only time that an elk was observed crowding the snow line in 1972. The great majority were scattered over the range between 8400 and 9000 feet. They were in small groups of 10 or less, and were seen feeding on green south- and west-facing slopes. The calves were born in this area. No calves were noted in areas of complete snow cover. In fact, all but a very few were born at least a mile from snow.

Old winter snow goes through three stages as it melts in the higher country. It is very hard and coarse-grained at the beginning of the spring period. As it melts, the upper surface gets wet and soft and the bottom layer starts to melt. As long as the weather remains cold and the depth stays about 24 inches, the snow is still hard enough to support an elk, man, or vehicle. On warm afternoons, snow depths of 12 inches get too soft to support elk. As the snow melts, it becomes even softer and

will not support a man. All these stages can be encountered on a warm afternoon in May when going uphill on a road or going from an open windswept park into the timber at the higher elevations. These physical conditions of snow allow elk to travel on top of deep snow through the timber to get to open parks or meadows at higher elevations. They do not have to move through soft heavy snow except along the edges where it is less than a foot thick. We drove a jeep over a five-foot-deep snowdrift at 10,000 feet on July 4.

The first complete snow cover in the fall above 9600 feet came just before a flight on September 30. At that time there were only a few elk tracks seen on the head of June Creek, Douglas Creek and the middle fork of the Little Laramie River in the estimated 4 inches of wet snow. Two flights during the deer hunting season, on October 3 and October 6, revealed very few fresh tracks in the old snow above the 9800-foot elevation. The elk were well scattered from the snow line down to the sagebrush foothills of South Mullen Creek at 8400-foot elevation.

The fall snow storms appear to have a definite effect on elk moving to the lower country. Even the light 4- to 6-inch snow cover moved animals from the higher parks. During the hunting season there are some movements of elk back into the deeper snow, which is probably a direct result of the presence of hunters. After 10 days of deer hunting during the first part of October, and the 16 days of elk hunting the latter part of October, it was unusual to see elk feeding on open slopes. Only in the more remote areas were elk seen, and they seemed reluctant to leave the dense lodgepole pine stands where they retreat when being hunted.

Elk proximity to logging operations

There were four separate clearcut logging operations active within the elk range during the period the telemetered elk were above 9000-feet elevation. Logging locations and the relative size and shape of the resulting clearcuts are shown in Figure 2, along with the location and size of the elk herds seen either from the air or ground. It was quite apparent that the elk preferred to stay at least one-half mile from people involved in timber harvest.

The data from fecal counts and time-lapse cameras at the head of Nelson Park and Middle Park show a great reduction in elk use during 1972 as compared to 1971, most likely a result of logging activities. Fecal group counts and time-lapse camera data are as follows:

		Cameras (hrs:min)		Fecal Counts (60 1/100 acre plots)	
		Elk	Sheep		
Location	Year	feeding	feeding	Elk	Sheep
Middle Park	1971	12:54	826:16	231	121
	1972	- - -	- - -	120	0
Nelson Park	1971	117:40	5322:36	139	33
	1972	2:35	- - -	5	0

Both Middle and Nelson Parks had considerable use by elk during the early summer, but it was usually at least one-half mile from the logging operations. The plot in Middle Park shows more pellet groups than in Nelson Park. It was farther from the timber harvest areas and separated by a fair stand of spruce and fir timber.

Elk proximity to logging roads

The logs were hauled from clearcuts on four different routes, (Fig. 2). Elk proximity to these roads is quite frequent. From these records it is doubtful if logging traffic has a major effect on elk movement. Telemetered cows 1, 2, 3 and 6, with their associates, crossed three of these roads several times during the summer. In fact, Cow 6 was killed less than one-fourth mile from the road from Cottonwood Creek to Foxpark, site of an active sawmill.

Elk proximity to mule deer

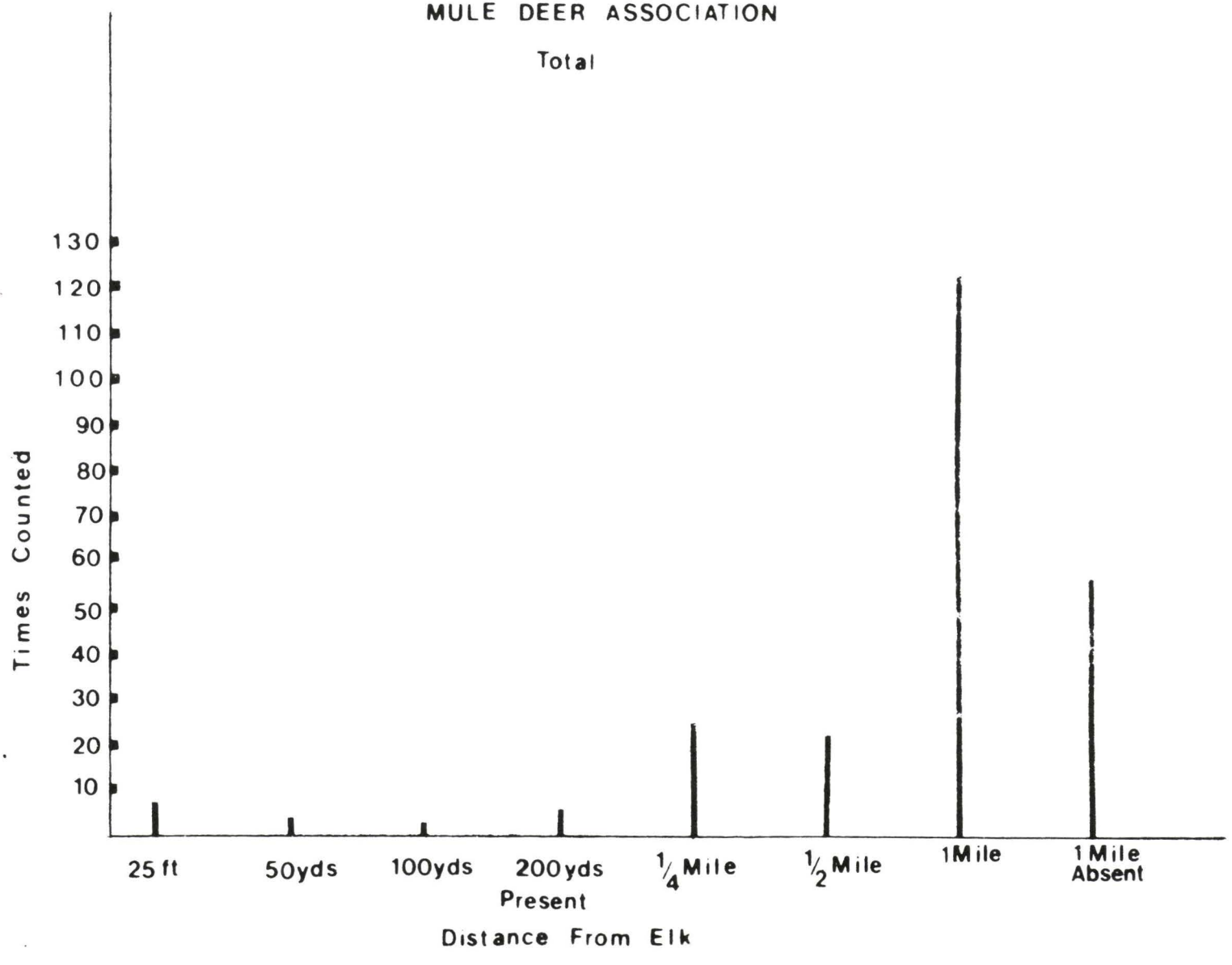
There is considerable interest in the interspecific relationship of elk and mule deer on many western ranges. To help understand this relationship, mule deer were looked for each time elk were fixed or seen, and the distances recorded. The deer are much harder to see from the air, so the data are less adequate. Figure 4 is a graphic summary of our observations. There were more close encounters recorded during the March - to - May period, which may be a reflection of better visibility due to the more open ridges being used by the animals. We also made more trips on the ground during this period which would help in seeing deer.

There were no observations that would indicate the two species are incompatible socially. The deer do not show the herding characteristics of elk during the summer and were distributed over the entire elk range.

Elk proximity to livestock

Cattle grazed from July to September on two Forest Service allotments where marked elk were seen. The Platte allotment was used by 390 animal units of Hereford cows with calves. This allotment is east of the North Platte River, from French Creek south to Douglas Creek. The Douglas Creek allotment was used by only 120 out of the 459 animal units allowed. The

Figure 4. Association of mule deer with elk.



part grazed in 1972 was the Lake Creek and Muddy Creek drainages on the east end.

All of the telemetered elk had left the lower sagebrush and aspen type slopes when the cattle came on the Platte allotment. Some elk were seen back in this area before the cattle left in the fall. Although they do not occupy the same range at the same time, there is considerable overlap in grazing throughout the year.

Telemetered cow 2 and her associates spent all summer in the Lake Creek and Muddy Creek drainage with the Hereford cows and their calves. On two occasions the elk were seen feeding within 200 yards of the cattle. The elk were seen feeding within one-half mile of cattle five times. They were very seldom over one mile apart. If the elk preferred to get away from the cattle, they had only to travel a few miles.

Horses were observed within 200 yards of elk on three occasions. These species appear to be compatible as long as food is plentiful.

Elk proximity to recreation

Recreation use of the area occupied by the marked elk and their associates is variable and considered to be moderate. The good roads and campgrounds are conducive to recreational vehicle traffic. In 1971, 2,950 vehicles traveled to and from the Platte River on the access road, and there is considerable traffic on the old logging roads into the more remote areas.

The major recreation is camping, picnicing, fishing, hiking, motoring, and hunting. The Forest Service recorded over 30,000 visitor-days camping and over 50,000 visitor-days big game hunting in the area in 1971. The elk preferred to stay about one-half mile from people associated with out-of-vehicle activity. They were frequently seen within 100 yards of vehicle

traffic, particularly in areas where the open parks are shielded from the roads by thick timber. This situation was particularly noticeable along Horse Creek road where cow 3 and her associates were often seen.

Vegetation data

Data on plants available to elk on known feeding sites are being recorded. A summary of this data will be prepared when measurements are completed.

Elk were seen in clearcuts during the early part of the season in June and July and again the latter part of August and September. The common plants in the clearcuts receiving regular use by elk were ebony sedge (Carex ebenea), common dandelion (Taraxacum officinale), lupine (Lupinus argentous), broom snakeweed (Gutierrezia sarothrae), wild buckwheat (Eriogonum umbellatum), and grouse whortleberry (Vaccinium scoparium). There were 23 times (involving 249 animals) when elk were seen feeding in clearcuts. The largest numbers were in the clearcuts at the lower elevations of Devil Gate Creek.

Observations on mule deer

In the course of the elk investigation, it became apparent that the mule deer in the study site were quite sensitive to snow accumulation. Because of their relative proximity during the elk study field work, some preliminary data on this species were collected during the summer of 1972. The data collected are essentially baseline in nature. It is envisioned that the present snow-impact study could be conducted simultaneously on elk and mule deer without additional cost or dilution of the quality of the elk research. For this reason, we are recommending that this investigation follow the previous research plan and procedure, but include both elk and mule deer.

There is a paucity of information concerning mule deer response to snow accumulation. Wallmo and Gill (1971) suggested that deer movements were hindered by snow. They found that during heavy-snow winters in Middle Park, Colorado the availability of winter range was so reduced as to severely limit the carrying capacity of the range and reduce the population. Gilbert et al. (1970) reported that the distribution of mule deer on winter range in Middle Park was largely governed by snow depth. In a review of deer harvests in Colorado, Peterson (1970) concluded that extremes of snow, wind and temperature altered normal deer distribution and behavior; and Kelsall (1969) found that both deer and moose movements were hindered by snow.

To accurately assess the effect of increased snow accumulation, basic information on deer populations, distribution, migration routes and behavioral patterns on the target area are needed. Investigations were begun this past July to collect these data, the field work being accomplished coincident with the elk study.

Deer observations were made along four different observation routes. Each route was driven approximately once each week. Animals seen on these routes were counted and classified by sex and age; sites where deer were located were characterized as to habitat type, geographical location, aspect and percent slope. The proximity of deer to other animals, roads and human activity was also noted. Droppings were collected when possible and stored for later analysis. In addition, two deer were captured by drugging with succinyl choline chloride and outfitted with radio transmitter collars.

Animal observations grouped according to sex and age are listed in Table 8. The number of does listed in the table includes adult and

TABLE 8

(DEER STUDY)

SEX AND AGE RATIOS OF DEER
SEEN ON THE SUMMER RANGE

1972

Category	Number	%
Doe	189	55
Fawn	96	28
Spikes & 2-Points	31	9
Buck	27	8
TOTAL	343	100

yearling animals. The results indicate a 2:1 ratio of does to fawns; the ratio of does to bucks is 3:1. In subsequent counts an attempt will be made to distinguish between adult and yearling does. Fawns were not as visible in the early part of the summer and the resulting doe:fawn ratio is probably high.

Habitat types where deer observations were made are listed in Table 9; the activity at the time of sighting is also indicated. The most frequent activity recorded was feeding. Willow-grass types and clear-cut areas were the most important feeding sites. Feeding also took place in open stands of coniferous trees. In late August and September this open coniferous forest apparently became more important than clear-cuts for feeding, at least during the day time. The study area contained large stands of thick timber, particularly lodgepole pine where resting, ruminating and hiding activities were usually observed.

An adult doe was outfitted with a radio transmitter on September 21, 1972, near Rob Roy Reservoir at an elevation of 9,500 feet. The deer was next located October 6, 1972, on School Creek at an elevation of 7,900 feet. This was a movement of approximately 16.1 air miles in 15 days. A yearling doe was outfitted with a transmitter on September 9, 1972, at Keystone, Wyoming at an elevation of 9,000 feet. She was next located in South Mullen Creek on October 6, 1972, at an elevation of 7,800 feet, a movement of approximately 14.7 air miles in 26 days. During the same period there was a noteable decrease in the number of deer observed on the summer range. This decrease may have been due either to the initiation of migration or occupation of low visibility habitat by the deer.

Prior to the beginning of autumn deer movements, very little snow fell on the study area. At the time of migration of the radio-outfitted

deer, little or no snow accumulation was present below 10,000 feet. Further information is needed to determine what factor or factors control the chronology of deer migrations on this area and what factors ultimately determine the length of use by deer of their winter, intermediate, and summer ranges.

TABLE 9

(DEER STUDY)

HABITAT TYPES WHERE DEER WERE OBSERVED
AND ACTIVITIES AT THE TIME OF SIGHTINGS
ON THE SUMMER RANGE, 1972

Habitat type	ACTIVITY											
	Feeding		Resting		Ruminating		Hiding		Walking		Running	
	#	%	#	%	#	%	#	%	#	%	#	%
Willow-grass	152	44.0	3	0.9	-	-	-	-	-	-	6	1.7
Clear-cut	65	19.0	-	-	-	-	-	-	2	0.6	2	0.6
Closed conifer	5	1.5	-	-	1	0.3	10	3	8	2.3	8	2.3
Open conifer	38	11.0	1	0.3	1	0.3	10	-	1	0.3	4	1.2
Grass Meadow	14	4.1	-	-	1	0.3	-	-	2	0.6	4	1.2
Aspen	5	1.5	-	-	-	-	-	-	-	-	-	-
TOTALS	279	81.1	4	1.2	3	0.9	20	6	13	3.8	24	7

IMPACT OF SPRING RUNOFF ON TROUT AND THEIR FOOD

Baxter and Loar

Earlier studies of brook trout ecology in the Medicine Bow Mountains were made on lake populations (Stewart 1959, Hepworth 1959, Royer 1960, Sinn 1961, Garofalo 1964, Christensen 1965, White 1965). Because of the close relationship between stream ecology and snowmelt runoff, our primary emphasis is on stream fisheries, with special attention to annual differences in growth of brook trout and the standing crop and production of stream invertebrates. The years 1970 and 1971 were years of heavy snowpack and runoff in the Snowy Range, but in 1972 the snowpack and runoff were considerably lower. The strategy of the present study is to compare the growth and production rates of trout and trout-food organisms between years of substantially different snowpack. A detailed study of stream invetebrates, now near completion as a Ph. D. thesis by William R. Good, University of Wyoming, was conducted during 1970 and 1971, making available data on standing crop densities of stream invetebrates that can be compared with data now being collected. Also, with some limitations the use of the scale method for calculating annual growth rates of fish makes it possible to compare growth rates of fish between different years. An examination of the relationships between precipitation, runoff, water temperatures and probably other environmental features is also a part of this study, together with the influence of these factors on trout and

trout-food production. Some lakes were also sampled for fish populations.

Methods

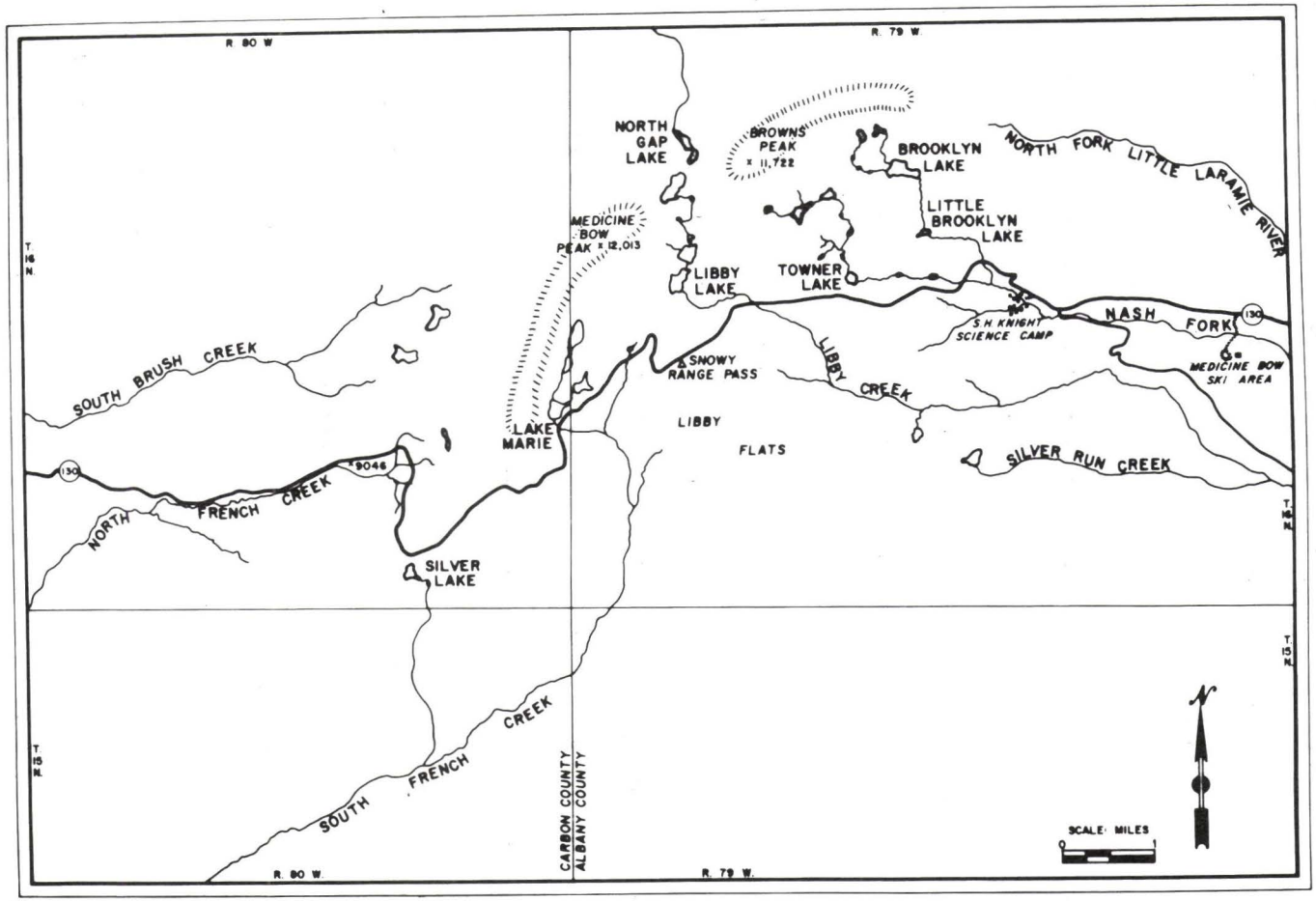
Weather data and stream flow data for the Snowy Range area have been collected by the Water Resources Research Institute, Univeristy of Wyoming since 1965 and are available for our research. In addition, water temperature is now being measured by means of Moeller recording thermographs (on a year-round basis in the Nash Fork Creek). During late July and August, 1972, thermographs were also installed at the North French Creek, Telephone Creek, and Sally Creek study areas.

Stream invertebrates were sampled using an enclosed one-tenth meter-square sampler constructed of fiberglass and netting. Invertebrates sampled were placed without sorting or picking in jars and preserved in approximately 10% formaldehyde. Samples are being hand-picked in shallow pans and stored for future sorting, enumeration and weighing. Preliminary maps of the stream study areas on Nash Fork Creek and North French Creek were prepared. These study sections were then subdivided according to bottom type, including large gravel, small rubble, large rubble, boulders and bedrock. The lengths of the resulting subdivisions were measured by pacing and scaled off on the maps. Several sampling transects were then located in each subdivision by means of a table of random numbers. From three to six samples were taken on these transects at varying intervals as required to avoid overlap, the number depending on the width of the stream at that transect. The samples taken in July and August were also located by a random numbers table. If the depth or velocity of the current made sampling physically impossible, an alternate sampling location was selected.

In Sally Creek and Nash Fork Creek an additional sampling scheme was used in order to provide a different kind of comparative data. A stratified random sampling design (Elliot, 1970) was used on both streams. A 480 meter section of Sally Creek extending upstream from the mouth of the stream was selected for this sampling. This section was subdivided into thirty-two 15 meter sections, samples being taken along a transect across the stream within each of these sections. The location of each transect was determined from a table of random numbers. For purposes of making comparisons between Nash Fork and Sally Creek, a 480 meter section of Nash Fork Creek with the midpoint at the mouth of Sally Creek was divided into twenty 24 meter subsections and sampled by the same method used for Sally Creek.

Samples of fish for studies of growth were collected by dip-netting, electrofishing and gill netting. Fish of several age groups were collected by approximately three week intervals from late June to early September. Fish were preserved in formalin and weighed and measured after preservation. Scales for growth analysis were cleared and mounted on glass slides and photographed.

Population estimates were made by a standard mark-and-recapture method, using an electrofishing apparatus. The Nash Fork study area, where the only population estimate was made in 1972, was subdivided into six sections approximately 120 meters in length and a separate estimate was made for each section. Fish were marked by a fin-clip, weighed and measured, and released into the same subsection of stream where collected. In order to ascertain whether there was movement of fish from a section, a different fin was clipped for the upper three subsections than for the lower



Map showing streams and lakes that are being studied.

three. The sections were sampled a second time within 48 hours. Population estimates were calculated from marked fish recaptured in the second sample using the equation: $\hat{N} = \frac{M(C + 1)}{R + 1}$, where

$\hat{N}$ = estimated number in the population
M = the number marked in the first sampling
C = the number collected in the second sampling
R = the number of marked fish recaptured in the second sample.

Confidence limits were set on the population estimate $\hat{N}$ by considering the number of recaptures R to be a Poisson variable, so that its square root is an estimate of its standard deviation, as recommended by Rounsefell and Everhart (1953, p. 92). Another precaution against downstream drift of marked fish consisted of electrofishing one additional 120 meter section below the study area in the second sampling.

Measurements of downstream drift of fish were made using overpour traps of simple construction consisting of a screen catch-box situated below a waterfall, either natural or produced by emplacement of a log across the stream. A hardware cloth screen of 1/8 inch mesh then bridged across from the top of the waterfall to the catch-box to provide a chute which remained flooded with water and which directed downstream-drifting trout into the catch-box. In some habitats this device functioned very well, in others few or no trout were captured; further evaluation of this technique is needed.

Description of streams and lakes

Data were gathered from the following streams and lakes:

1. Nash Fork Creek. 1000 meter section at the S. H. Knight Science Camp. R79W-T16N-S13 and 14. Elevation 9940 to 10,000 feet.

2. Sally Creek. 480 meter section from the mouth upstream. R79W-T16N-S13 & 14. Elevation 9880 to 10,000 feet.
3. North French Creek. Approximately 1500 meter section upstream from the bridge crossing on the North French Creek Road. R80W-T16N-S29. Elevation 9560 to 9700 feet.
4. Towner Lake and its inlet stream about 300 meters upstream. R79W-T16N-S15. Elevation 10,500 feet.
5. Libby Lake, and its outlet stream 200 meters downstream. R79W-T16N-S17. Elevation 10,700 feet.
6. Silver Lake. R80W-T16N-S35. Elevation 10,400 feet.

Nash Fork Creek at the study area is a torrential montane stream with a July volume flow of about 50 cfs, and velocities of as much as 4 feet per second. The bottom type in the study area includes bedrock, boulders (>12"), large rubble (8" - 10"), medium rubble (5" - 8"), small rubble (2" - 5"), and coarse gravel (3/4" - 2"). The upper end of the section is at the confluence of Nash Fork Creek with Telephone Creek in the canyon above the S. H. Knight Science Camp. The lower end is at the upper end of a series of meanders containing several beaver ponds, in the meadow below Camp. Sally Creek joins Nash Fork Creek about midway in the study section. The invertebrate fauna, to be described in detail in later reports, includes a variety of mayflies, stonefiles, caddis flies, diptera, and a few beetles and non-insect invertebrates. The fishery is a mixed one which includes brown trout, brook trout and a few rainbow trout. The brown and brook trout populations are self-sustaining, the rainbows are for the most part planted. Fishing pressure is heavy in the meadow below the study area and moderate to light in the study area itself. The only non-game species of any significance in the area is the longnose sucker.

In August, 1972, the dissolved oxygen content of the water was 6.5 to 7.1 ppm, Methyl Orange alkalinity was 50 ppm., the pH was 7.4. Dissolved carbon dioxide was not measured. Water temperatures are discussed in a separate section of this report.

Sally Creek is a small montane stream with a July volume flow of 4 to 5 cfs and with a velocity of usually less than 3 feet per second. The bottom type is mixed gravel and rubble. The invertebrate fauna is somewhat less diverse than that of Nash Fork Creek. The fishery consists of a sparse population of brook trout and a few brown trout. Fishing pressure is light. Water temperatures are substantially lower than those in Nash Fork Creek. In 1972 the water in Sally Creek did not warm to 50° F until June 30; the water of Nash Fork Creek reached 50° F on June 18. The maximum temperature recorded in Sally Creek in 1972 was 59° F on July 16; in the Nash Fork Creek the maximum temperature was 66° F, recorded on July 18.

North French Creek drains the west slope of the Snowy Range, joining the South Fork and entering the North Platte River in Carbon County. It is a montane stream of similar volume flow but with less maximum velocity than Nash Fork Creek. A Parshall flume was not installed in North French Creek by WRRI until August, 1972, so comparative flow data are inconclusive as yet. The upper end of the study area in this stream is a meandering section with alternating slow riffles and pools and a bottom of coarse gravel mixed with sand. The lower half of the section is of steeper gradient, greater velocity and with a bottom type principally of rubble. The invertebrate fauna includes most of the same species occurring in Nash Fork Creek, but with a higher percentage of the diptera and beetles which

prefer a stream habitat with slower velocities. The fishery in North French Creek is made up entirely of a relatively dense population of brook trout. Because the stream parallels Highway 130 for several miles in this area, the fishing pressure is relatively heavy. Unfortunately the trout population suffered an epidemic of a bacterial kidney disease in July of 1972. Although the mortalities to the resident fish population were low, this epidemic interferred with the conduct of the present study in that special precautions had to be taken to guard against spreading this disease to other habitats in the Snowy Range. This disease was diagnosed by Douglas Mitchum, fish pathologist, Wyoming Game and Fish Department and, on his recommendation, sampling of the fish in this study area was discontinued in 1972 after the diagnosis was made. Dissolved oxygen content in this stream section was 6.3 ppm on July 6; Methyl Orange alkalinity on this date was 21 ppm. The water temperatures recorded for North French Creek in 1972 indicate that water temperatures of this stream and Nash Fork Creek are essentially identical.

Preliminary Results

Measurements of streamflow in different sections of the Nash Fork Creek drainage show a reduced runoff in 1972 compared with that in 1970 and 1971, Table 1. As indicated earlier, this lower runoff coincides with a lower amount of snow.

Table 1. Streamflows measured at four locations, Nash Fork Creek drainage, during 1970 through 1972. Measurements are sec.-ft.-days.

Year	Sally Creek		Nash Fork (0106)		Nash Fork (0111)		Tel. Creek	
	June	July	June	July	June	July	June	July
1970	394	142	3593	1635	1050	718	784	655
1971	576	250	3652	2507	1168	790	756	872
1972	379	59	3335	784	1283	410	712	293

A warm spring in 1972 produced a sudden runoff which is reflected in the relatively high flows measured in June, 1972; the flows for July are considerably less than previous years.

Stream water temperatures are listed in Table 2. A comparison of temperature data with the stream flow data in Table 1 suggests cooler water temperature with increased flow rate, but further analysis of this data is required.

Table 2. Water temperature data recorded from Nash Fork Creek, 1970 through 1972.

Year	Date Temp. reached 40 F.	Date Temp. reached 50 F.	Max. Temp. and Date
1970	June 13	June 22	62 F., July 9, July 16
1971	June 19	June 26	63 F., July 16
1972	June 6	June 18	66 F., July 18, July 19

The growth rates of brook trout fry, fingerlings (young of the year), and yearlings are shown in Tables 3 and 4. These fish were collected from four different habitats at approximately three week intervals. In the case of the fry-fingerlings, the absolute growth rates and ultimate size attained appear to be greatest for Nash Fork Creek where it exceeded the growth of fish either at North French Creek and at the subalpine lakes which lie at higher elevation and have lower prevailing water temperatures. These data are deceiving, however, and probably reflect more than anything the fact that the fry emerged from the spawning gravels a week or ten days earlier in Nash Fork Creek. A similar trend in growth is seen in the yearling fish, where the Nash Fork Creek fish seem to grow somewhat faster. The differences are not great, however. More detailed analysis of these

Table 3. Mean total length and weight of brook trout yearlings collected in 1972.

Habitat	Nash Fork Creek			North French Creek			Libby Lake Outlet			Towner Lake		
Date	No.	L. (mm)	W. (gm)	No.	L. (mm)	W. (gm)	No.	L. (mm)	W. (gm)	No.	L. (mm)	W. (gm)
June 29	12	70.0±11.0	4.11±i.8*									
July 20	13	88.4±7.6	8.74±2.4									
Aug. 10	10	100.4±11.4	12.28±3.7									
Aug. 22	5	100.4±5.4	12.24±2.6									
Sept. 1	9	102.0±7.3	11.74±2.51									
July 6				21	58.6±6.5	2.48±.8						
July 27				10	77.1±7.9	5.8±1.7						
June 29							10	66.7±9.9	3.44±1.64			
Aug. 9							1	89.0±0.0	8.28±0.0			
June 22										20	61.0±5.6	2.50±73
July 13										39	75.8±7.28	5.24±1.10
Aug. 4										13	92.0±5.4	8.97±1.37

* = standard deviation

Table 4. Mean total length and weight of brook trout fry-fingerling collected in 1972.

Habitat	Nash Fork Creek			North French Creek			Libby Lake Outlet			Towner Lake		
Date	No.	L. (mm)	W. (gm)	No.	L. (mm)	W. (gm)	No.	L. (mm)	W. (gm)	No.	L. (mm)	W. (gm)
June 29	32	21.9±3.5	.12±.07*									
July 20	26	39.5±7.00	.71±.3									
Aug. 10	14	46.2±8.3	1.15±.6									
Sept. 1	15	62.2±7.4	2.72±1.0									
July 6				21	19.6±1.3	.073±.01						
July 27				32	26.3±2.60	.190±.07						
July 20							17	23.7±1.7	.099±.03			
Aug. 9							20	32.8±3.9	.442±.15			
Sept. 1							17	50.7	1.64			
July 13										32	22.6±2.3	.135±.045
Aug. 4										34	35.2±4.2	.509±.21
Aug. 31										30	54.9±5.3	1.870±.55

* = standard deviation

growth trends needs to be completed before any definitive conclusions can be drawn.

Results of the population estimate made on the Nash Fork Creek trout population are shown in Table 5. The calculations can be carried out in a number of ways with little difference in the final estimate of 406 fish in the 720 meter section of stream studied, with a 95% confidence interval of 317 to 607 fish. The percentages of the different species based upon the ratios of these in the total number of unmarked fish collected in the experiment were brook trout 54.4%, brown trout 39.5%, and rainbow trout 6.1%. As shown from the estimates calculated for the individual sections, brook trout predominated in the lower three sections, and brown trout in the upper three sections. This may be the result of habitat preference on the part of the two species, or the proximity of the lower section to the beaver ponds in the meadow below the study section where brook trout are quite abundant. Population pressure could be forcing some fish upstream into the lower part of the study section.

Little in the way of conclusions is possible until the analysis of the invertebrate data and fish scales is completed. Data presented in this report show that 1972 was a year of reduced runoff, in comparison with the two previous years, and water temperatures in Nash Fork Creek were also warmer. Brook trout in the young-of-the year and yearling age classes grew faster in habitats at lower elevations,and faster in the Nash Fork drainage than in the French Creek drainage. The major influences on growth are yet to be determined, whether available food, water temperature, time of fry emergence, or some other factor. We will examine specifically those factors that could be affected by winter precipitation management.

Table 5. Results of the mark-and-recapture program for a population estimate, Nash Fork Creek, August, 1972.

Section*	Brook Trout M	C	R	$\hat{N}$	Brown Trout M	C	R	$\hat{N}$
1	25	20	7	66	9	9	3	22
2	23	15	4	74	7	5	2	14
3	11	10	5	20	8	13	4	22
4	4	3	1	8	9	10	3	25
5	4	8	1	18	9	8	0	81
6	6	11	4	14	5	8	2	15
Total				200				179

* Six rainbow trout were marked in the first sample; nine were collected in the second sample, including three recaptures.

Using the combined data for only brook and brown trout: M = 120, C = 120, R = 36, $\hat{N}$ = 392 with confidence limits (95%) 304 to 599.
Using combined data including rainbows: M = 126, C = 128, R = 39, $\hat{N}$ = 406, with confidence limits (95%) 317 to 607.

Plans for Next Year

Plans for next year will not be finalized until the data collected in 1972 are more completely analyzed. Tentative plans include the following:

1. More thermographs will be placed early in the spring in habitats where growth measurements of brook trout are to be made, and more careful monitoring of air and water temperature will be continued into the fall.
2. The maps will be refined by additional measurements of gradients and flow rate.
3. Sampling of brook trout and invertebrates will be duplicated, but on a smaller scale as prescribed by statistical analysis of the 1972 data.
4. Trout food will be studied in more detail to establish the relationships between stream invertebrate production and trout growth and to examine the relationships between available food, water temperature, and growth of fish.
5. If the outbreak of bacterial kidney disease in the brook trout in North French Creek recurs in 1973, a different stream section will be selected in the French Creek drainage.

THE IMPACT OF SPRING RUNOFF ON MOUNTAIN LAKE ENERGY FLOW

Parker, Czaplewski, and Condit

Systems analysis in a mathematical sense is the approach being used for the lake studies. There are two major phases to the research program that are being pursued simultaneously, 1) the construction of a mathematical model of energy flow in a lake based on existing information, and 2) the collection of data from certain lakes to validate the model. The model, when validated, can then be used to predict the effects that winter precipitation management might have on the lake ecosystem, in particular energy flow. Perhaps the most direct effect of increased snow will be an increased flushing rate resulting from increased spring runoff. Temperatures might also be lowered. Flushing rate and temperature are two factors that are built into the model, and can be varied in order to simulate ecosystem response.

The mathematical model has already been constructed and is operative on the University of Wyoming computer system, though refinement is still required. Also, the validation data are still incomplete. Until further refinement and validation are accomplished, there is little reason to describe the model at length in this Progress Report.

In general, the model contains eight compartments measured in terms of carbon content, with flow rates of carbon into and out of each compartment (Fig. 1). The model behaves as expected under simple conditions. If no phytoplankton are present, other compartments decline to zero. With constant light and temperature, and no fish present, all

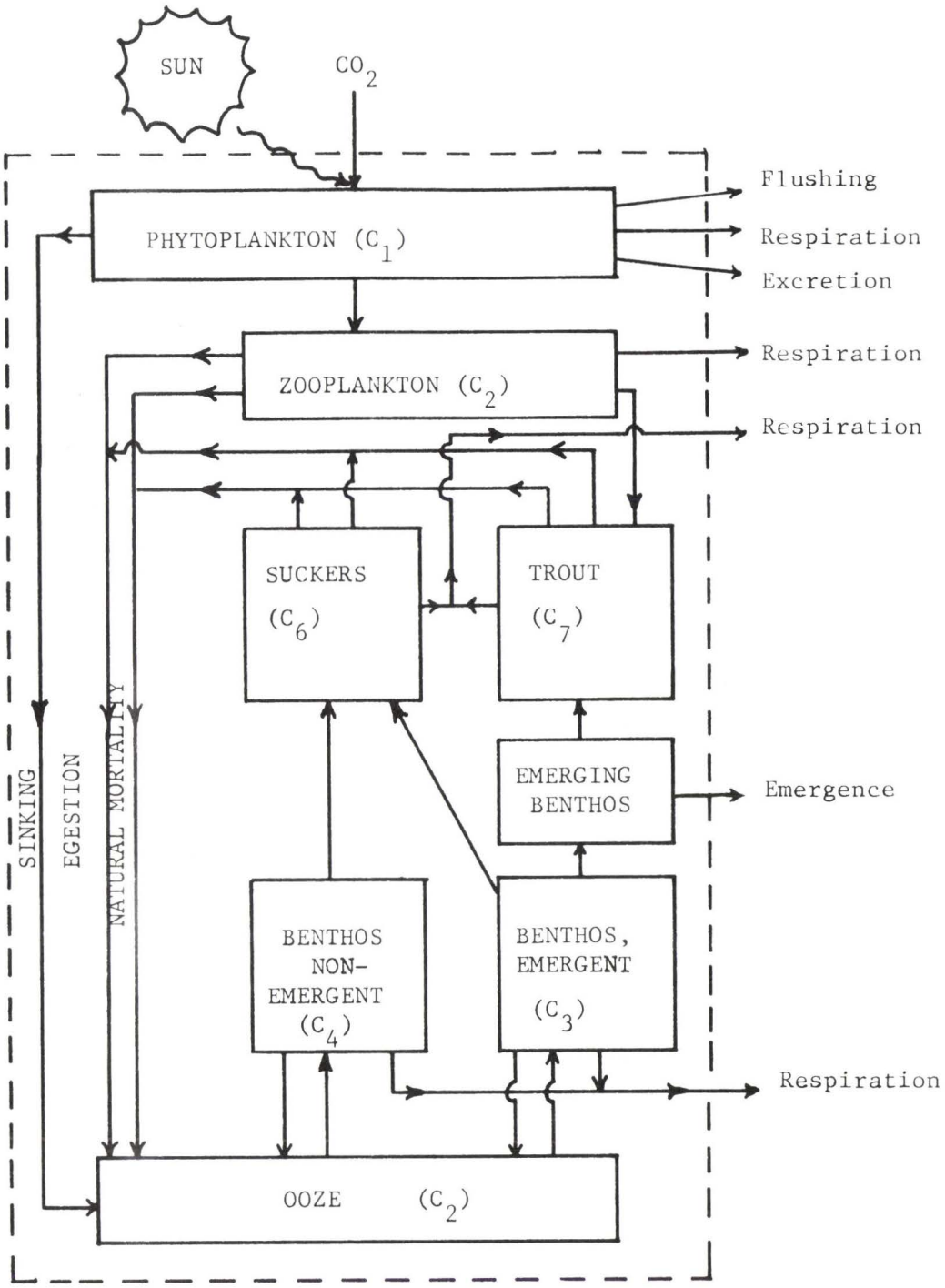


Figure 1 (Lake Study). A compartmental model showing the major compartments and flows being considered in the mathematical model.

compartments stabilize within three to four months. Phytoplankton standing crop oscillates with an oscillatory light input. Actual phytoplankton biomass measurements from Libby Lake average 0.4 gCm^{-3}, with a maximum of 0.9. The simulation model now produces the same order-of-magnitude of phytoplankton biomass, but two peaks occur and it is not known that annual bimodal peaks actually occur in Libby Lake.

Because the benthos samples are still being picked, and zooplankton counts have not yet begun, we cannot compare measured and simulated values for these compartments. The model generates very large oscillations between benthos and fish, although they may begin to damp-out by the end of the 10 year simulation that we have run. There do appear to be oscillations in benthic standing crop in Medicine Bow Mountain lakes, but certainly not of the magnitude generated by the model. Solutions for controlling these oscillations are discussed below.

The function generating the temperature of the epilimnion obviously needs to be modified. The temperature in Libby Lake on 28 June was only about 8°C, while in the model this temperature was reached in early May. The dates of initiation and termination of ice cover also need to be corrected, and this can be done easily.

The value for the extinction coefficient of light (k) used in the model is very close to the values measured in the lake. The next refinement to be added is a function modifying k depending on the amount of particulate matter brought into the lake by runoff.

The function calculating the reduction in solar energy due to ice cover will be evaluated pending results from this winter's field work. Also, we have yet to include a term reducing solar energy input due to reflection at the air-water interface.

The function calculating stream input in m^{-3} day^{-1} will initially be modified to reproduce flow rates actually observed this past summer. Later an attempt will be made to increase the realism of this function based on a hydrologic submodel.

The behavior of phytoplankton in the model seems quite reasonable. We are considering adding a compartment for dissolved inorganic carbon (CO_2). The program will calculate two conditional production rates, based on production realized if either light or CO_2 were limiting. The program will then choose actual production rate to be the minimum of these two conditional rates. This would necessitate accounting for all respiratory inputs, of diffusion across the air-water interface, and probably inclusion of bacteria. This will require additional computer time, a disadvantage. One advantage gained will be an evaluation, or check, on the realism of the balance between photosynthetic uptake and respiratory output of carbon. That is, to insure that the pool of dissolved CO_2 does not "blow-up" or vanish, which is a check on rates of input and output.

The next change of the zooplankton compartment (C_5) will be a loss due to flushing:

$$\text{Flushing loss (g C/d)} = (\text{stream outflow})(C_5)(k) \quad (26)$$

From the literature, the value of k appears to be between 0.4 and 0.8. We may also eventually divide the zooplankton into two compartments, representing small and large animals. This is because clearly all zooplankton are not equally vulnerable to predation by trout.

Ooze, benthos and fish are all closely interrelated in the model. The interrelations presently described by the model lead to violent oscillations, and additional controls are necessary.

At present the only loss from the ooze compartment is via ingestion by benthic organisms. It seems appropriate to include an additional loss via bacterial respiration. Also, in terms of food for benthic organisms, the carbon represented by settled phytoplankton is probably much more available than that in settled egested material. It may also be worthwhile keeping track of ooze depth, since at most only the upper few cm are available to the benthic organisms in the lake.

We are considering combining the emergent and non-emergent benthos (compartments C_3 and C_4) into one compartment, primarily because both feed on the same resource, ooze, and if the feeding efficiency of one is greater it will displace the other. That is, we have two "species" occupying the same niche. Elimination of one compartment takes some time because of the magnitude of the rates involved, but will occur. We originally made two compartments because, based on data, we felt that merging benthos was an important source of food for trout. The compartments may be lumped, with the emerging benthos easily retained in the model as food for trout, if two major assumptions are valid. First, the ratio of standing crops, emerging/nonemerging, must be relatively constant. Limited data suggest that this assumption may be reasonable. The second assumption is that the major mechanism(s) regulating the standing crop of all benthic organisms operate while the organisms are on the bottom. That is, if even just a few emerging insects escape predation, enough eggs will be laid so that there is no effect on the benthic population the next year. Actually, this assumption is presently being used.

Another limitation of the present model is that there is no upper limit to benthic standing crop. This is unreasonable since in addition to the space occupied by each individual, many species sweep clear an area

of bottom surrounding their burrow. Hence, based on spatial considerations there should be an upper limit to the standing crop.

Cursory inspection of the benthos samples taken this summer indicates that the standing crop is very low in deep water. This is probably a function of oxygen availability. It can most easily be incorporated into the model by reducing the limit on standing crop in deep water in an empirically determined manner. Eventually, of course, this should be done via a calculation of oxygen depletion. This will necessitate an additional compartment for oxygen, with appropriate inputs and outputs. Calculating oxygen depletion would also be useful to modify the functions describing benthic respiration and the benthic feeding of fish.

An over simplification of the fish compartment interactions is that there is probably considerable predation by trout on young suckers as they return to the lake from streams. Such seasonal predation can easily be incorporated into the model.

Another important simplification is that there is no provision for emigration or imigration, especially for trout. Data from overpour traps and experiments removing fish from small ponds show marked movement by the trout in the Snowy Range (Baxter, personal communication). These movements can be included in the model by a simple emigration coefficient, positive at low standing crops, zero over a range of intermediate levels, and negative at higher levels. It might also be reasonable to have a similar function for suckers.

Finally, trout should feed to some extent on benthic organisms living on the bottom. This will necessitate developing weighting or preference factors for each type of food utilized by the trout, and a limit to the total rate of ingestion. That is, the trout will feed at a

rate which is a function of total food abundance as described by a hyperbolic ingestion function, but total abundance of food will be calculated by summing the weighted abundance of each type of food.

In summary, we are very encouraged by our modeling efforts to date. We constructed the model independently of other workers. However, we discovered that our basic approach and even the values for many parameters (assimilation, respiration, etc.) were almost identical to a successfully working model developed in conjunction with the Canadian International Biological Program.

Preliminary results of 1972 field work

Field work during 1972 was designed to provide data that would be useful for model validation. Temperature was measured with a Whitney underwater thermometer (Model TC-5A), and light with a submarine photometer (G.M. Manufacturing Co., Model 268 WA 300). pH was measured with a Beckman model N pH meter. Measurements of dissolved oxygen were made with an oxygen probe (Yellow Springs Instrument Co. Meter Model 154, Probe Model 5418) and by the Winkler method as described by Carpenter (1965). Alkalinity was determined by the indicator method outlined in Standard Methods (American Public Health Association, 1971) and chlorophyll was measured by the acetone extraction method using a Beckman DU spectophotometer and the equations of Strickland and Parsons (1968). Productivity was measured by the light and dark bottle oxygen method and the ^{14}C method (Vollenweider, 1969).

All water samples were taken with a non-metallic Van Dorn water sampler. Quantitative (240 mls) and qualitative phytoplankton samples were taken in both lakes at the surface, and quantitative samples were taken at 3m intervals. These samples were concentrated for enumeration

by the Utermohl method (Lund, Kipling, and LeCren, 1958).

Zooplankton samples were obtained with a Clarke-Bumpus sampler (G.M. Manufacturing Co., Model 012 WA 300 F) with a #20-mesh net and bucket. Quantitative and qualitative samples were taken from 11m to 6m and from 6m to the surface in Libby Lake at Station I, and from 5m to the surface at Station II. Attempts were made to sample the outlet using the Clarke-Bumpus sampler, but this method did not work well. In Silver Lake quantitative and qualitative samples were taken from 7 m to 4 m and from 4 m to the surface.

Benthos was sampled in Libby Lake along two transects which were divided into meter intervals. The actual location of sample stations along these transects for any given sample was determined from a random numbers table. Two Ekman dredge samples were taken at each station. Twelve stations were sampled on transect 1 and eight on transect 2. One transect of eight stations was sampled on Silver Lake. Welsh (1948) was used as a general reference for the above methods.

Data from Libby Lake appear in Tables I - VII, and data from Silver Lake in Tables VIII - XIV.

The light and dark bottle oxygen method proved unsatisfactory in Libby Lake because the lake is not very productive. The ^{14}C method was then used on Libby Lake and on Silver Lake. We are presently in the process of standardizing the ^{14}C and our counter so that the data may be analyzed.

Preliminary taxonomic work has been done on the concentrated phytoplankton samples from Libby Lake and counting will soon begin. The following genera have been identified: Asterionella, Tabellaria, Anabeana, Staurastrum, and Peridinium. There are several diatoms, a desmid, and a filamentous green algae yet to be identified. The chlorophyll data

(Tables VII A, VII B) show that the standing crop of Libby Lake phytoplankton has a major peak in September and a much smaller peak in early August. There may have been another peak in late June before sampling began. The zooplankton data have not yet been analyzed.

The benthos samples are now being picked. Taxonomic work and measurements of dry weight will commence when the picking is finished.

An experiment was conducted to partition the light extinction coefficient (k) into the extinction due to water alone and the extinction due to suspended particulate material. The results of this experiment have not yet been analyzed.

Particulate nitrogen samples have not yet been analyzed.

The temperature in Libby Lake reached a measured maximum of about 14.5° C in mid-August. Methyl orange alkalinity was constant during the summer, and phenolphthaline alkalinity appeared only in mid-August. pH also remained fairly constant throughout the summer, with a slight increase in early August coinciding with the small phytoplankton peak. Through the summer dissolved oxygen increased slightly in the upper 9m of the lake, but decreased by 50% in the lower 3m.

In Silver Lake the temperature increased until mid-August, reaching a maximum value of 16°C. There was a strong tendency for the lake to stratify thermally at 4m. Alkalinity increased until mid-August, and was higher at the bottom of the lake than at the surface. pM also increased during the summer. Dissolved oxygen remained constant in the epilimnion of the lake, but dropped sharply at 6m. The chlorophyll data show a maximum phytoplankton standing crop in August.

The work schedule for the next quarter includes analysis of ^{14}C data, beginning the phytoplankton counts, finishing the picking of

benthos samples, taxonomic work on zooplankton samples, and winter sampling of the lakes. Most work will be done on Libby Lake.

TABLE I. LIBBY LAKE SAMPLING DATES AND PARAMETERS SAMPLED

Two Stations were sampled from July 12 to August 18.

Date	Temp.	Light	Alkalinity	pH	Oxygen Winkler	Oxygen Probe	Chlorphyll	Particulate Nitrogen	Productivity	Phytoplankton	Zooplankton	Benthos
6/28/72	X	X	X		X					X	X	
7/5		X								X		
6	X						X		X		X	
7	X		X	X	X	X			X			
11	X			X		X				X		
12	X	X	X	X						X	X	
13			X	X	X				X			
18	X	X	X	X			X	X		X	X	
19												X
25	X	X	X	X		X	X	X				
8/2/72	X	X	X	X	X	X	X	X		X		
4												X
8	X	X	X	X	X	X	X	X		X	X	
9		X	X	X					X	X		
10									X			
16	X	X	X	X	X	X	X	X		X		
17												X
18												X
9/16/72	X	X	X		X		X			X	X	

TABLE II A. TEMPERATURE OF LIBBY LAKE IN °C AT STATION I.

Date	Air	0m	0.5m	1m	2m	3m	4m	5m	6m	7m	8m	9m	10m	11m	12m
June 28, 1972		7.0	9.6	9.6	9.6	9.4	8.8	8.3	8.0	7.9	7.8	7.6	7.5	7.2	6.8
July 6	19.8	10.7	10.6	10.8	11.1	12.6	11.8	10.8	8.4	7.9	7.7	7.7	7.6	7.6	7.5
7	10.0	10.2	10.2	10.2	10.2	10.1	10.0	8.9	7.0	7.0	6.5	6.5			
11	12.4	11.1	11.1	11.3	11.2	11.5	11.0	10.6	9.6	7.9	7.7	7.5	7.4	7.2	
12	18.4	11.6	11.6	12.0	11.9	11.5	11.3	11.1	9.0	7.5	7.4	7.2	7.0	7.0	6.9[a]
18	11.2	11.8	11.7	11.7	11.7	11.6	11.3	11.1	10.7	10.4	10.1	9.0	7.0	6.8	6.5
25	12.7	11.9	11.9	11.9	11.9	11.9	11.9	11.8	11.5	11.1	9.8	8.4	7.6	6.9	6.7
August 2	14.5	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.6	11.2	9.7	7.7	7.3	7.2
8	27.1	13.4	13.3	13.1	12.7	12.7	12.4	12.2	11.9	11.7	11.6	11.0	9.3	7.8	7.6
16	21.9	14.5	14.0	13.5	13.5	13.4	13.2	13.0	12.9	12.4	11.2	10.5	9.4	8.4	8.3
Sept. 16	6.5	6.7	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8				

a. taken at 11.5m

TABLE II B. TEMPERATURE OF LIBBY LAKE IN °C AT STATION II.

Date	Air	0m	0.5m	1m	2	3	4	5
July 12, 1972	16.2	11.9	11.6	11.3	11.2	11.1	11.0	11.0
18	11.2	11.7	11.8	11.8	11.7	11.6	11.4	11.4[a]
25	12.7	12.0	12.0	12.0	12.0	11.9	11.9	11.9
Aug. 2	15.3	12.0	12.0	12.0	12.0	12.0	11.9	11.8
8	17.6	14.6	14.3	14.1	13.4	13.2	12.9	
16	19.2	15.1	15.0	14.9	14.4	13.4	13.2	12.8

a. taken at 4.5m

TABLE III A. LIGHT EXTINCTION COEFFICIENTS M^{-1} (k) AND PERCENT OF TOTAL LIGHT PENETRATING THE AIR-WATER INTERFACE OF LIBBY LAKE AT STATION I.

DATE	K	% TOTAL LIGHT AT 0m
June 28, 1972	0.5188	103[a]
July 5	0.5176	86
12	0.5055	66
18	0.4175	75
25	0.4822	52
August 2	0.4953	
8	0.5390	
9	0.4425	
16	0.5301	48
Sept. 16	0.3266	82

[a]error in readings.

TABLE III B. LIGHT EXTINCTION COEFFICIENTS M^{-1} (k) AND PERCENT OF TOTAL LIGHT PENETRATING THE AIR-WATER INTERFACE OF LIBBY LAKE AT STATION II.

DATE	K	% TOTAL LIGHT AT 0m
July 12, 1972	0.3530	66
18	0.4175	80
25	0.4695	48
August 2	0.5023	58
9	0.4425	
16	0.4023	

TABLE IV A. ALKALINITY (ppm) AS $CaCO_3$ IN LIBBY LAKE AT STATION I.

DATE	0m		3m		6m		9m		11m	
	Phth.	M.O.	Phth.	M.O.	Phth.	M.O.	Phth.	M.O.	Phth.	M.O.
June 28, 1972	0	3[a]	0	9			0	9	0	11
July 7[b]										
12	0	9			0	8			0	11
13	0	8	0	8	0	8	0	9		
18	0	9	0	8	0	8	0	8		
25	0	9	0	10	0	9	0	8	0	9
August 2	0	9	0	8	0	9	0	8	0	8
8	0	8	0	8	0	9	0	9	0	10
9	0	9	0	9						
16	<1	9	<1	11	<1	13	<1	13	<1	13
Sept. 16	0	8	0	7[c]	0	7[d]				

a. error in titration

b. potentiometric method did not work

c. taken at 4m

d. taken at 7.5m

TABLE IV B. ALKALINITY (ppm) AS $CaCO_3$ IN LIBBY LAKE AT STATION II.

DATE	0m		3m		4m		5m	
	Phth.	M.O.	Phth.	M.O.	Phth.	M.O.	Phth.	M.O.
July 12, 1972	0	8					0	10
18	0	8	0	8				
25	0	8	0	8				
August 2	0	8	0	9			0	9
8	0	9	0	9	0	9		
9	0[a]	9[a]	0	10				
16	<1[a]	11[a]	<1	10			<1	10

[a] taken at 0.5 m

TABLE V A. LIBBY LAKE pH AT STATION I.

Date	0m	0.5m	3m	6m	9m	11m	11.5m	12m
July 7, 1972	6.6		6.6[a]	6.6[b]	6.7			
11	7.2							
12	7.0			7.0		6.7		
13				6.9	7.2			
18	6.7		6.8	6.8	6.5			
25	6.8[c]		6.9[c]	7.4	7.4		6.5	
August 2	7.4		7.4	7.5	7.3			6.7
8	7.4		7.9	7.7	7.1			6.4
9		7.2	7.5					
16		8.7	8.8	8.3	6.6		6.4	

a taken at 4m

b taken at 8m

c meter not standardized

TABLE V B. LIBBY LAKE pH AT STATION II.

DATE	0m	0.5m	3m	5m
July 12, 1972	7.0			
18	6.8		6.7	
25	6.9		7.1	
August 2	7.4		7.5	7.3
8	7.5		7.9	8.0
9		7.4	7.4	
16		8.1	8.9	8.6

TABLE VI A. DISSOLVED OXYGEN (ppm) IN LIBBY LAKE AT STATION I.

W indicates values obtained from Winkler titrations

P indicates values obtained with an oxygen probe

Date	Method	0m	0.5m	1m	2	3	4	5	6	7	8	9	10	11	12
June 28,1972	W	7.7				7.4					7.7			7.7	
July 7	W											11.7			
	P	6.5	6.5	6.5	6.5	6.6	6.6	6.8	6.8	6.6	6.3	6.1			
11	P	6.4	6.4	6.3	6.3	6.3	6.4	6.4	6.7	6.6	6.0	5.6	5.4	4.7	
13	W			7.9[a]		7.9[b]		7.7	7.8			6.8			
25	P	8.0	7.6	7.6	7.5	7.5	7.5	7.4	7.4	7.3	7.3	7.0	6.0	5.3	3.5
August 2	W	8.2							8.0						
	P	7.5	7.4	7.3	7.3	7.4	7.4	7.4	7.4	7.3	7.2	6.4	5.0	4.0	2.9[c]
8	W	7.6													
	P	7.9	7.9	7.9	7.8	7.2	7.2	7.2	7.1	7.2	6.5	3.9	2.7	2.7	2.1[c]
16	W	8.2							7.8						2.3[c]
	P	7.0	7.0	7.0	7.1	6.9	6.8	6.7	6.8	6.2	6.0	4.2	3.2	2.0	1.5[c]
Sept. 16	W	7.3					7.3			7.0[d]					

a taken at 1.5m

b taken at 3.5m

c taken at 11.5 m

d taken at 7.5 m

TABLE VI B. DISSOLVED OXYGEN (ppm) IN LIBBY LAKE AT STATION II.

W indicates values obtained from Winkler titrations

P indicates values obtained with an oxygen probe

Date	Method	0m	0.5m	1	2	3	4	5
July 25, 1972	P	7.7	7.6	7.6	7.6	7.6	7.5	7.5[a]
August 2	W	8.0				7.9		
	P	8.2	7.8	7.8	7.8	7.7	7.6	7.6
8	W	7.6						
	P	7.7	7.7	7.7	7.8	7.8	7.7	
16	P	8.5	8.5	8.5	8.6	8.7	8.6	8.4

a taken at 4.5m

TABLE VII A. CHLOROPHYLL a, b, and c (mg M^{-3}) IN LIBBY LAKE AT STATION I.

ND means not detected.

DATE	Chlorophyll	0m	0.5	1.5	3	5.5	6	9	10	11.5	outlet	inlet
July 6, 1972	a		1.38	2.78[a]		6.52			3.43			
	b		2.07	1.02[a]		4.34			2.89			
	c		3.38	3.72[a]		7.11			ND			
18	a	1.82										
	b	0.80										
	c	1.38										
25	a	2.49			2.76		4.47	17.79		26.01		
	b	0.23			0.14		0.99	2.99		7.13		
	c	ND			0.28		2.55	1.70		0.04		
August 2	a	4.61			4.47		4.15	5.70		18.66		
	b	0.96			1.14		0.58	1.96		4.19		
	c	0.27			1.50		ND	1.38		ND		
8	a	4.93			5.61		6.48	5.20		4.44	3.96	
	b	2.25			2.58		4.05	4.35		3.37	3.01	
	c	ND			ND		ND	0.37		2.14	ND	
16	a	8.09	9.54	6.68	9.25		9.71	7.75		6.59[b]		10.53
	b	3.68	1.72	1.75	3.30		4.24	3.92		2.63[b]		3.14
	c	2.52	0.51	ND	1.32		ND	1.02		0.61[b]		0.10
Sept. 16	a	16.65			15.17[c]			16.99[d]				
	b	1.63			1.12			1.43				
	c	1.90			3.66			4.60				

a taken at 1.6 m
b taken at 12 m
c taken at 4 m
d taken at 8 m

TABLE VII B. CHLOROPHYLL a, b, and c (mg M^{-3}) IN LIBBY LAKE AT STATION II.

ND means not detected.

Date	Chlorophyll	0m	0.5m	1.5m	3m	4m
July 18, 1972	a	1.72			1.34	
	b	0.71			0.96	
	c	0.58			2.42	
25	a	2.91				
	b	0.48				
	c	0.81				
August 2	a	4.39				
	b	0.44				
	c	0.36				
8	a	4.81			4.79	24.31
	b	2.57			0.21	21.14
	c	ND			7.07	11.13
17	a		8.67	9.61	9.15	
	b		2.24	1.29	0.70	
	c		1.50	2.47	0.56	

TABLE VIII. SILVER LAKE SAMPLING DATES AND PARAMETERS SAMPLED

Date	Temp.	Light	Alkalinity	pH	Oxygen Winkler	Oxygen Probe	Chlorophyll	Particulate Nitrogen	Productivity	Phytoplankton	Zooplankton	Benthos
7/21/72	X		X	X	X					X	X	
26	X	X	X	X	X	X	X	X		X		
27												X
8/3/72	X	X	X	X	X	X	X	X		X		
8			X	X			X		X	X		
9		X							X			
10	X		X	X	X			X		X	X	
14												X
16			X				X		X			
17	X	X	X	X	X	X	X	X		X	X	
9/16/72	X	X	X	X	X		X	X		X	X	

TABLE IX. TEMPERATURE OF SILVER LAKE IN °C

Date	Air	0m	0.5m	1m	2m	3m	4m	5m	6m	7m	7.5m	8m
July 21, 1972	15.8	13.4	13.4	13.4	13.3	12.2	9.8	7.0	5.8	4.7	4.6	
26	11.7	13.5	13.6	13.6	13.7	13.0	11.6	8.1	6.7	5.5	5.1	
August 3	16.3	13.4	13.4	13.3	13.3	13.2	12.4	9.8	7.9	6.9		6.1
10	26.8	16.0	15.8	15.5	15.3	15.2	14.4	12.0	9.8	9.5		8.6
17	13.5	15.0	15.0	15.0	14.8	14.5	14.0	12.3	10.5	9.7		8.3
Sept. 16	18.9	10.8	10.7	10.6	9.9	9.7	9.6	9.5	9.4	9.2	9.2	

TABLE X. LIGHT EXTINCTION COEFFICIENTS M^{-1} (k) AND PERCENT OF TOTAL LIGHT PENETRATING THE AIR-WATER INTERFACE OF SILVER LAKE

Date	K	% Total Light at 0m
July 26, 1972	0.6338	52
August 3	0.6183	
9	0.3686	84
17	0.5726	78
Sept. 16	0.3260	82

TABLE XI. ALKALINITY (ppm) AS $CaCO_3$ IN SILVER LAKE

Values are for methly orange alkalinity (no phenolphthaline alkalinity present).

Date	0m	0.5m	1.5m	3	4	6	7	7.5
July 21, 1972	10			14		0	24	
26	15			15		22		26
August 3	15			12	14	18	24	
8	14	15	15					
10	16			15		23		30
16	16	14	15					
17				14		21		25
Sept. 16	12			12			12	

TABLE XII. SILVER LAKE pH

DATE	0m	0.5m	1.5	3	4	6	7	7.5
July 21, 1972	6.8			6.7		1.7[a]		
26	7.2			7.2		6.5		6.4
Aug. 3	7.5			7.6	7.4	6.7	6.6	
8	7.6	7.6	7.6					
10	7.6			7.5		6.6		6.5
16	7.8	7.9	7.6					
17				7.4		6.8		6.7
Sept. 16[b]	7.5			7.6			7.4	

a low value possible due to unclean sampling bottle

b samples sat for 6 hours before pH was measured

TABLE XIII. DISSOLVED OXYGEN (ppm) IN SILVER LAKE

W indicates values obtained from Winkler titrations

P indicates values obtained with an oxygen probe

Date	Method	0m	0.5m	1	2	3	4	5	6	7	7.5	8
July 21,1972	W	7.0				8.7			4.5	4.14		
26	W	7.2				7.9			4.6		0.2	
	P	6.3	6.1	6.0	6.0	6.4	8.7	6.8	2.7	0.8	0.6	
Aug. 3	W	7.3				7.5	8.0		4.7			
	P	6.5	6.5	6.5	6.4	6.4	7.2	6.9	4.3	1.2		0.8
10	W	7.5							5.5			
17	W	4.9							2.7			
	P	6.8	7.0	6.9	6.9	6.9	6.9	7.8	5.3	3.5		1.4
Sept.16	W	7.1				7.1				7.0		

TABLE XIV. CHLOROPHYLL a, b, and c (mg M^{-3}) IN SILVER LAKE

ND means not detected

Date	Chlorophyll	0m	0.5m	1.5	3	6	7	7.5
July 26, 1972	a	0.93			1.22	5.03		
	b	0.29			0.12	0.88		
	c	1.18			0.12	0.61		
August 3	a	0.80			2.41	0.93	3.82	
	b	ND			1.73	0.44	1.00	
	c	ND			1.05	ND	ND	
8	a	0.69	0.92	0.67				
	b	0.23	0.43	0.49				
	c	0.08	0.91	1.35				
16	a	1.26	1.24	1.32				
	b	0.61	0.48	0.56				
	c	1.01	1.04	1.08				
17	a				1.47	3.46		14.31
	b				0.66	1.65		7.88
	c				1.21	1.41		5.22
Sept. 16	a	0.80			0.80[a]		3.28	
	b	0.54			0.14		0.38	
	c	0.34			0.50		0.95	

[a] taken at 3.5m

THE IMPACT OF SNOW ON LITTER DECOMPOSITION AND NUTRIENT LEACHING

Knight, Kyte, and Starr

The litter-decomposer environment is very different when snow is on the ground, being constantly cold (ca. freezing) and moist with little or no diurnal variation. After snow melt the litter dries rapidly, being moistened irregularly and infrequently by summer showers; the temperature is warmer but fluctuates dramatically with exposure to direct sunlight. Although it seems reasonable to think that most litter decomposition would occur with warmer temperatures, Bleak (1970) found that considerable loss of plant material could occur under snow in Utah mountain vegetation, and Stark (1972) reports that most of the cell content and nitrogen and phosphorous are removed from fresh pine litter during the first winter under snow. We plan to quantify decomposition in the winter and summer for several ecosystems of the Medicine Bow Mountains, with our objective being to predict the effect of longer snow duration on annual decomposition.

Nutrients released during decomposition may be lost from a particular ecosystem through leaching, a phenomenon governed in part by the amount of water moving through the litter and soil. During heavy snowfall years there may be more leaching and this could affect plant growth if nutrients are already limiting. Since winter precipitation management is intended to increase snow water on the mountains, will leaching of nutrients increase? Will the rate of eutrophication increase with cloud seeding, especially when combined with the intensive timber management now

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	b	ND			1.73	0.44	1.00	
	c	ND			1.05	ND	ND	
8	a	0.69	0.92	0.67				
	b	0.23	0.43	0.49				
	c	0.08	0.91	1.35				
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practiced in portions of the mountains?

The effect of increased snow on decomposition and leaching will be evaluated by means of a simple, small-scale experiment involving a snow treatment. Two null hypotheses will be tested in a spruce-fir forest, a lodgepole pine forest, and a subalpine meadow:

1. Longer persisting snow will not affect total annual litter decomposition.
2. Increased snow will not promote increased nutrient leaching.

All of the study areas are above 9,000 feet and hear Headquarters Park on the western slopes of Medicine Bow Peak.

Methods

Jordan tension-free lysimeters (Jordan 1968) have been installed in each of the three ecosystems (2 per pit, 4 pits per ecosystem) in order to evaluate leaching. Installation required first the digging of pits approximately 2 x 3 x 3 feet deep. Two tunnels with nearly flat tops were dug just below the major rooting zone, with dimensions of about 8 inches diameter by 15 inches long. The lysimeter trough was then firmly wedged against the tunnel ceiling. Water that percolates through the soil over the lysimeter is collected in the trough, where it then flows through rubber hose to a one gallon plastic bottle in the bottom of the pit. The pits are covered during the winter and the only source of water in the bottles is via the soil and collection trough. The water in the bottles will be tested periodically for nutrient content by the Wyoming State Chemistry Laboratory.

Litter bags made from 2 mm nylon mesh are being used to estimate decomposition rate. Five bags with Whatman No. 1 filter paper (a

cellulose substrate) and 5 bags with litter from the site have been placed near each of the 12 pits, for a total of 40 bags in each ecosystem. These bags were weighed before being placed in the field, and some will be weighed immediately after snow melt to determine winter decomposition. New bags will be positioned in the spring and collected in the fall to measure summer decomposition, and some bags will remain in place for one or more years.

In the meadow ecosystem, two of the four plots (each centered around a pit) will be subject to a snow treatment, with the other two (randomly selected) serving as controls. The snow treatment will consist of adding additional snow by shovel so that snow persists for approximately 14 days longer than on the control plots. The data will be analyzed to determine if the snow treatment has an effect on total decomposition and nutrient leaching.

In the forest ecosystems it has been possible to identify patches of ground where snow regularly persists longer, due either to irregular snow accumulation or irregular snow melt. This patchiness became evident through monitoring patterns of snow melt during 1972 and then observing that the vegetation was in fact different under longer persisting banks. Thus, a natural experiment is in process. Two pits were dug where banks are known to persist, thereby providing a natural snow treatment, and two pits were dug where snow usually melts at least 2 weeks earlier. As in the meadow, decomposition and leaching will be measured in order to test the null hypotheses.

Preliminary Results

The lysimeters and litter bags could not be installed until this past summer, and therefore no data will be available from this experiment

until next summer. Since differences could be very minute after just one year, it may be necessary to continue the experiment for several years. More lysimeters and litter bags will be installed if our first results indicate the need for a larger data base.

THE MOVEMENT AND CONCENTRATION OF SILVER IN THE MEDICINE BOW ECOSYSTEMS - Singleton and White

Introduction

Most precipitation management systems utilize silver iodide as a nucleating agent. It is conceivable that areas receiving artificially induced precipitation could accumulate silver iodide in amounts greater than received under natural precipitation. Ecosystem concentration processes are known to occur, but whether they would be effective or not with the small amount of silver used in cloud seeding is not known.

In anticipation of future cloud seeding in the Medicine Bow Mountains, a silver monitoring program has been established. Monitoring will supply the baseline values which will make it possible to detect whether any increases occur in silver content of the soil and plant communities as a result of cloud seeding. Other studies will help to determine the disposition of silver iodide in the ecosystem, as well as the amounts which can be expected to accumulate under given concentrations of silver. In addition, our studies will determine the possible effects of silver iodide on germination and plant vigor of species found in the study area.

Methods

Twenty silver monitoring sampling sites have been established in the Medicine Bow Mountains to give a fairly even geographic representation of the target area (Fig. 1). Sites were chosen which contain communities of aspen, spruce, lodgepole, and grass vegetation. Although this combination was not always found in close proximity, sites were chosen where the

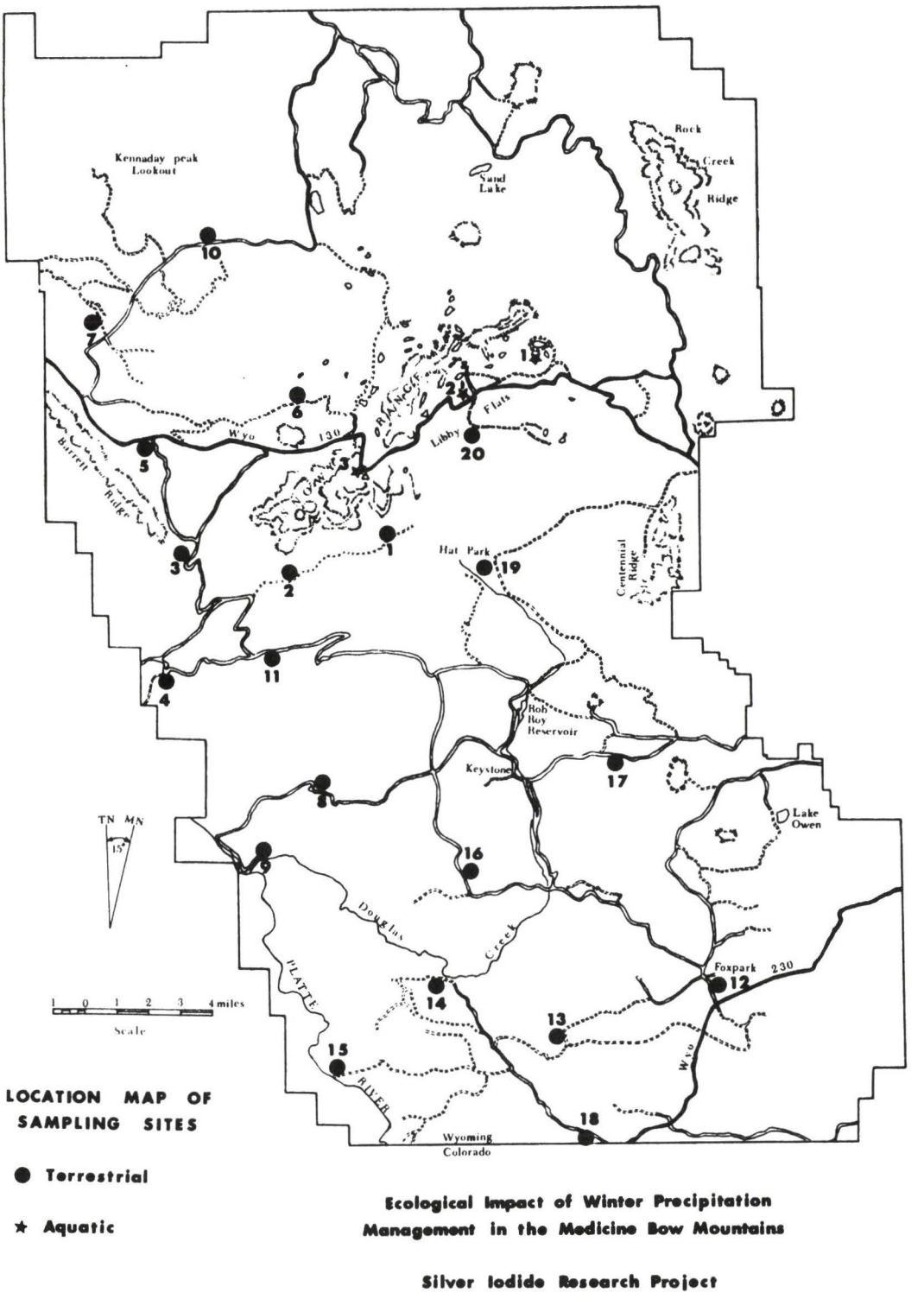


Figure 1 (SILVER MONITORING STUDY).

different communities could be found as close together as possible. Samples of soil, vegetation and litter have been collected from all tree communities, and soil and vegetation were collected from grass communities. Five trees from each forest community at each site were selected for sampling. Foliage collected from the five trees was combined into a composite sample to represent that community at that site. Soil and litter were also collected from under the same five trees and combined into composite soil and composite litter samples. Vegetation and soil were collected from a circular area of four meters in diameter at each grass community. In 1972, two samplings were taken, one in early June, and again in late September before the aspen leaves had fallen. The spring and fall samplings were conducted to determine if the silver content in the ecosystem undergoes seasonal fluctuations.

The samples were submitted to a commercial laboratory for silver analysis. The laboratory used the pyrosulfate fusion method for silver determination which involves drying, pulverizing and ashing the sample, fusion with potassium pyrosulfate, solution with nitric acid, extraction with TOTP-MIBK organic solvents (triisooctyl phosphorthioate - methyl isobutyl ketone), and determination of silver by atomic absorption. The detection limit for this method is 0.008 ppm Ag in ash. The data in this report are expressed as percent silver on both an ash and dryweight basis.

Plot Studies

Plot studies were also established in the Libby Flats area during the summer. This study is designed to determine the degree and rate of silver movement through the soil profile as a result of leaching by natural precipitation. The study will also indicate if the Ag content of plants can be influenced by the silver content of the soil. The

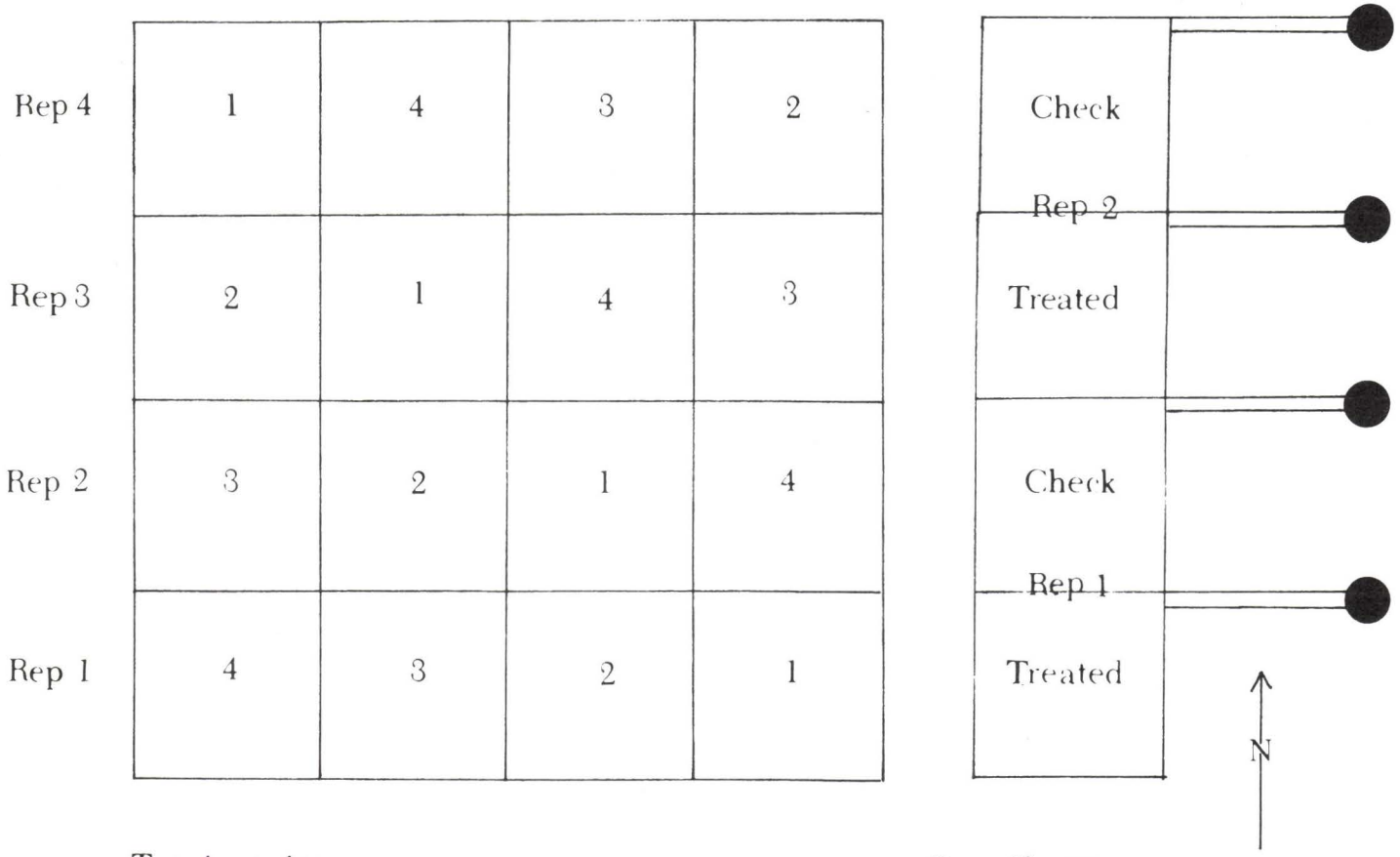
design of the study is a latin square consisting of 16 nine square meter plots (Fig. 2). There are four silver treatments replicated four times. The treatments consist of (1) a check containing 0.06 ppm natural silver content of the soil, (2) 0.12 ppm silver in the soil, (3) 0.24 ppm Ag in the soil, and (4) 0.48 ppm Ag in the soil. The Ag, as a colloidal suspension of AgI, was applied to the plots in August 1972. Soils and vegetation will be sampled from the plots in August of 1973 and analyzed for Ag. Different depths of the soil profile will be sampled to determine if silver has moved through the profile. Each of the plots is bordered by 4" galvanized steel lawn edging buried into the soil approximately two inches.

Another study adjacent to the above plots was initiated to determine if the Ag content of runoff water is influenced by the silver content of the soil (Fig. 2). This study consists of two treatments, (1) a check containing 0.06 ppm Ag in the soil, and (2) 0.48 ppm Ag in the soil, each replicated two times. These plots are also bordered with 4" galvanized steel edging to prevent lateral movement of the Ag from one plot to another. A pipe connects each plot to a buried container that will collect runoff water. Water collected during the spring runoff will be analyzed for Ag.

Greenhouse studies

In the fall of 1972, 24 small trees, approximately 2 feet in height, (12 lodgepole and 12 spruce) were collected from the study area and transplanted to pots in the greenhouse in soil from the study area. After about a month, adequate time for the trees to adjust to the transplant, they were contaminated with silver iodide. Four treatments were used, each treatment being replicated 3 times. The treatments were (1) a check containing 0.06 ppm natural silver in soil, (2) 10 times natural Ag content of soil, (3) 100 times natural Ag content of soil, and (4) 1000

Libby Flats Silver Study



Treatments:

1- Check (0.06 ppm natural Ag in soil)

2- Two times natural Ag in soil (approx 0.12 ppm)

3- Four times natural Ag in soil (approx 0.24 ppm)

4- Eight times natural Ag in soil (approx 0.48 ppm)

Plots are each nine square meters

Runoff Plots:

Plots were contaminated at eight times natural silver in soil. Runoff water is caught and tested for silver content.

Figure 2 (SILVER MONITORING STUDY). Layout diagram for the Libby Flats experiment.

times natural Ag in soil. These trees will be harvested in the fall of 1973 and analyzed for Ag content. The results should give some indication as to whether trees will accumulate Ag under different soil Ag concentrations, and indicate if there is a difference in Ag accumulation between the two species of trees.

Another greenhouse study has been initiated to determine the influence of Ag on seed germination and seedling development. Soil was collected for this study from under both grass and forest communities from the Medicine Bow Mountain study. The tree soil, after being screened to remove rocks and roots, was placed in pint cartons in the greenhouse and contaminated at 10, 100, and 1000 times the natural Ag concentration. This gives 4 treatments including the check, with each treatment being replicated 15 times. Four days after contamination, 50 lodgepole seeds, purchased from Clyde Robin Seed Company, Castro Valley, California, were planted in each carton. Germination counts will be taken as the seeds germinate to determine if any Ag effects can be detected. After about three months, above and below ground plant parts will be removed from each pot to determine if the different Ag treatments have affected total plant production. A similar study is planned, in which Tufted hairgrass seeds (Deschampsia caespitosa (L.) Beauv.) collected from the mountain study area will be planted in Ag-contaminated grass-community soil.

Preparations are also being made to conduct further germination tests of lodgepole, spruce, and Tufted hairgrass seeds in a germination chamber on Ag treated agar substrate. The seeds will be germinated in petri dishes on a 1.5% agar substrate treated with 4 concentrations of Ag, 0, 0.1, 10, and 100 ppm. A AgI suspension will be mixed with the agar while it is in a liquid state, the mixture autoclaved, and then poured

into sterile petri dishes. Fifty seeds of a species will be placed in each petri dish of the treatment series. The study will be replicated 4 times. A record of germination will be recorded over a specified period of time.

Preliminary Results

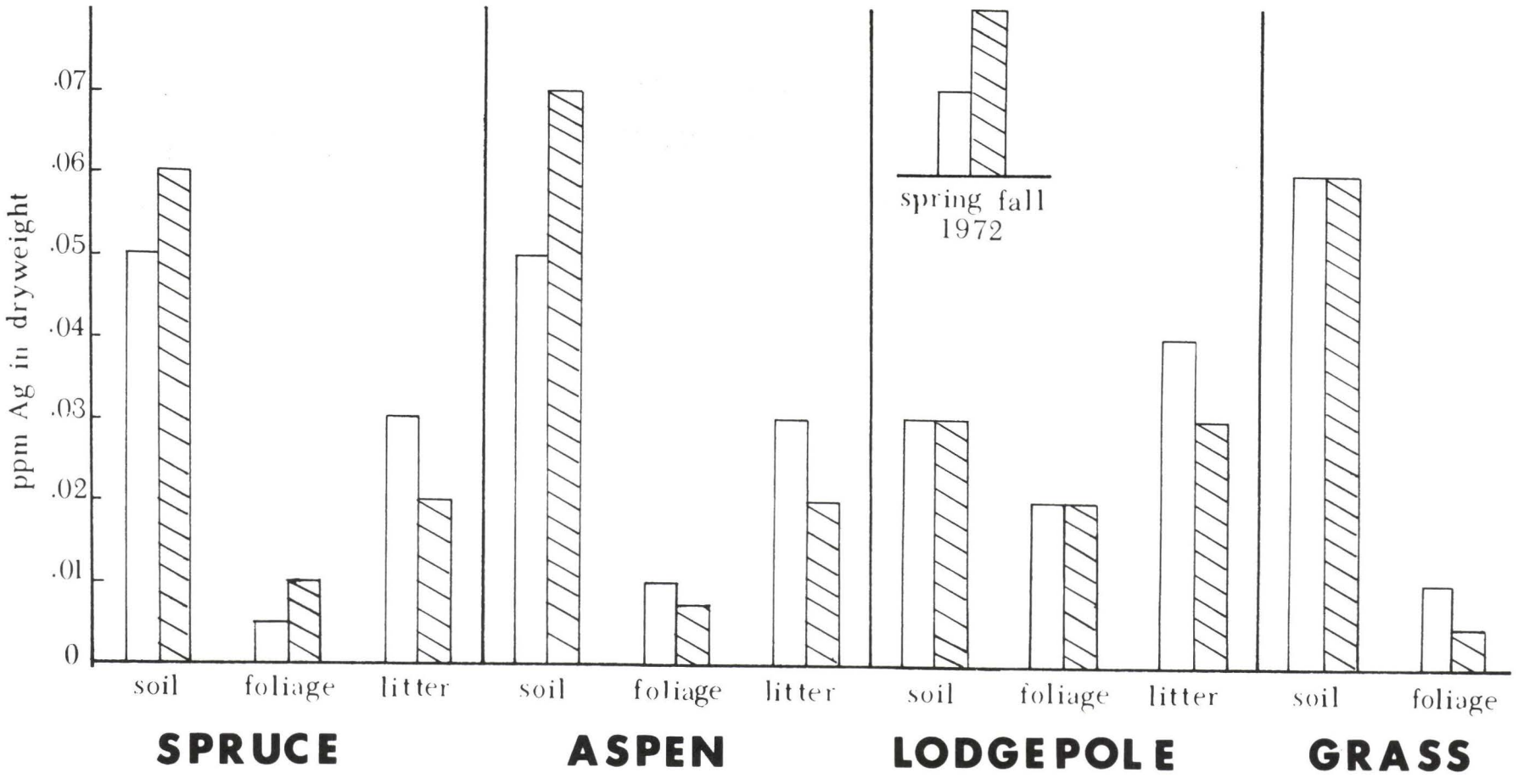
Summarized data for the Spring and Fall sampling of monitoring sites are found in Figures 3 and 4, and in Table 1.

Variability of silver content of soils, litter, and vegetation from the study area seems relatively high, but is somewhat less than that found in comparable data in the literature. Coefficients of variation ranged from 43 to 140 percent on a ppm ash basis as compared to 78 to 306 percent on a ppm ash basis on similar data collected in Colorado.

The comparison of silver content of components within species for the Spring 1972 sampling (dryweight basis) follows:

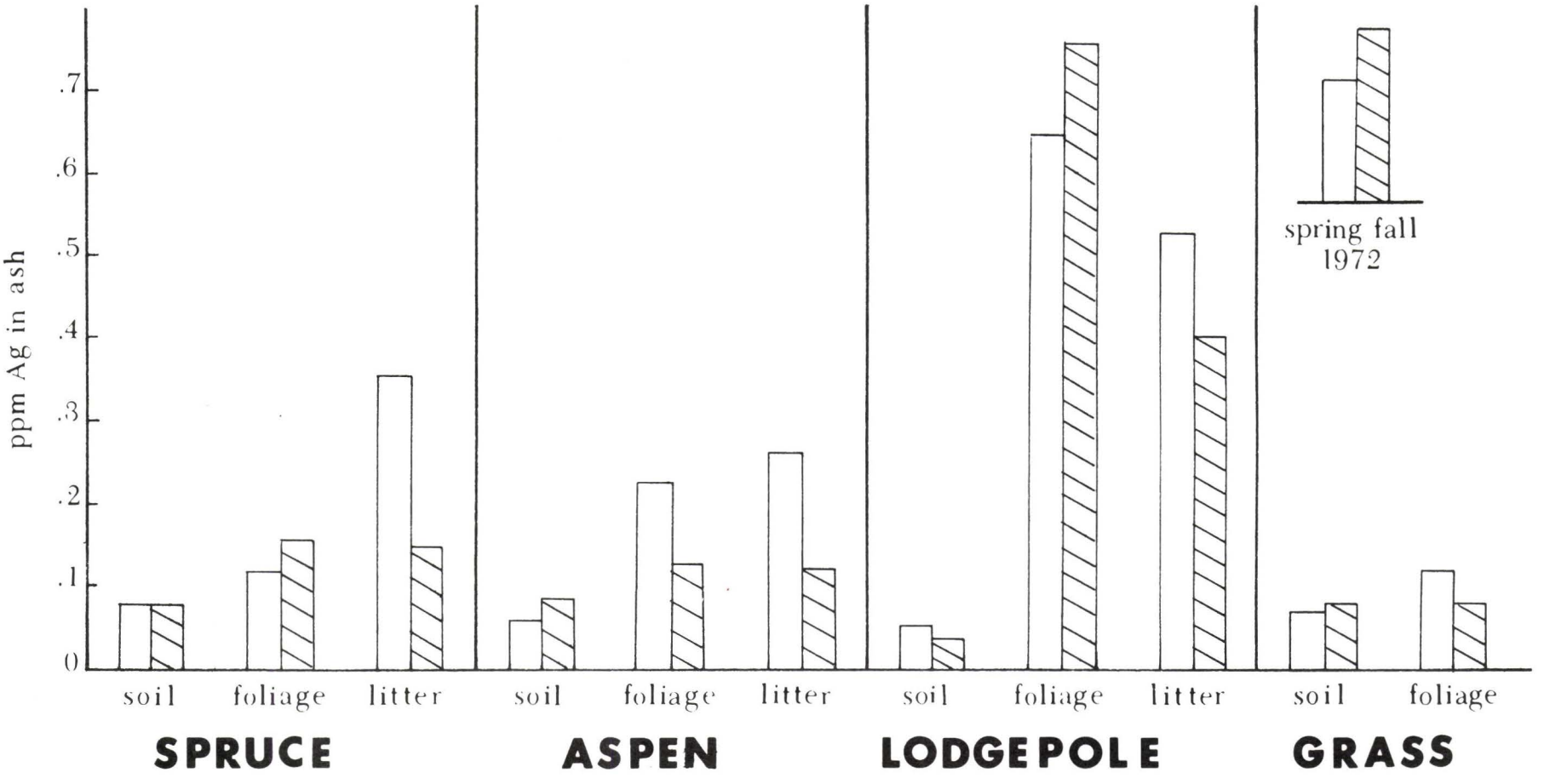
Grass community -	soil (0.060 ppm)	greater than	foliage	(0.008 ppm)
Aspen community -	soil (0.046 ppm)	greater than	foliage	(0.014 ppm)
	soil (0.046 ppm)	NSD*	litter	(0.033 ppm)
	litter (0.033 ppm)	NSD	foliage	(0.014 ppm)
Lodgepole community -	soil (0.034 ppm)	greater than	foliage	(0.015 ppm)
	litter (0.039 ppm)	greater than	foliage	(0.015 ppm)
	litter (0.039 ppm)	NSD	soil	(0.034 ppm)
Spruce community -	soil (0.054 ppm)	greater than	foliage	(0.004 ppm)
	soil (0.054 ppm)	greater than	litter	(0.033 ppm)
	litter (0.033 ppm)	greater than	foliage	(0.004 ppm)

*NSD - No significant difference



Mean silver concentrations in terrestrial components of Medicine Bow Mountains (dryweight basis)

Figure 3 (SILVER MONITORING STUDY).



Mean silver concentrations in terrestrial components of Medicine Bow Mountains (ash basis)

Figure 4 (SILVER MONITORING STUDY)

Table 1. Summarized data of the Spring and Fall samplings of the Ag monitoring sites in Medicine Bow Mountains -- 1972

	Component	No. of Samples	SPRING % Ash	1/ s.d.	ppm Ag in Ash	s.d.	ppm Ag dry wt.	s.d.	FALL % Ash	s.d.	ppm Ag in ash	s.d.	ppm Ag dry wt	s.d.
SPRUCE	Soil	20	92.2	6.8	.061	.062	.054	.052	90.6	5.4	.063	.072	.056	.063
	Litter	20	18.2	10.2	.339	.585	.033	.015	16.0	10.0	.035	.081	.018	.013
	Foliage	20	4.2	1.1	.105	.094	.004	.003	4.8	1.3	.147	.086	.007	.003
ASPEN	Soil	19	93.1	4.4	.051	.045	.046	.044	91.7	4.5	.073	.102	.065	.092
	Litter	19	14.3	4.3	.251	.144	.033	.020	17.1	6.8	.119	.078	.019	.013
	Foliage	19	6.5	0.8	.219	.213	.014	.014	6.8	1.4	.117	.053	.007	.004
GRASS	Soil	20	93.4	2.1	.065	.065	.060	.061	90.5	4.2	.068	.071	.061	.066
	Foliage	20	7.8	1.8	.113	.102	.008	.007	6.5	1.9	.072	.073	.004	.003
LODGEPOLE	Soil	19	94.5	2.3	.036	.042	.034	.037	94.1	3.0	.034	.040	.031	.035
	Litter	19	8.7	5.0	.517	.341	.039	.020	7.9	6.6	.400	.216	.025	.012
	Foliage	19	2.4	0.4	.637	.267	.015	.017	2.4	0.4	.753	.322	.018	.006

1/ Standard deviation of mean values in preceding column

On a dryweight basis, the concentration of silver is higher in the soil than in the foliage of all species. Spruce soil is thirteen times higher in Ag than foliage, whereas Lodgepole soil is two times higher than foliage. Soil is seven and three times higher than foliage in grass and aspen, respectively.

A comparison of Ag content between spring and fall sampling 1972 (dryweight basis) follows:

Foliage - Spruce - Fall (.007 ppm) greater than Spring (.004 ppm)
Grass - Spring(.008 ppm) greater than Fall (.004 ppm)
Aspen - No significant difference (NSD)
Lodgepole - NSD

Litter - Spruce - Spring (.033 ppm) greater than Fall (.018 ppm)
Aspen - Spring (.033 ppm) greater than Fall (.019 ppm)
Lodgepole - Spring (.039 ppm) greater than Fall (.025 ppm)

Soil - Spruce - NSD
Grass - NSD
Aspen - NSD
Lodgepole - NSD

The significance of these results will be discussed in the Final Report, when more data on silver concentration and silver disposition will be available.

Plans for next summer

The silver monitoring sites in Medicine Bow Mountains will again be sampled in the spring and fall of 1973. The soils and vegetation from the experimental plots on Libby Flats will be sampled and analyzed for Ag content. Greenhouse studies will continue as previously described in the methods section of this report.

One Master's Thesis will be written at the conclusion of the project.

THE SENSITIVITY OF TROUT TO SILVER COMPOUNDS

Anderson and McCoy

Thus far the emphasis in this report has been on the ecological effects of additional snow fall. Another concern, however, is on the effects, if any, of silver on organisms in the Medicine Bow ecosystems. Silver iodide is the most widely used source of seeding nuclei, and fish have been found to be quite sensitive to silver nitrate (Cooper & Jolly 1969). Our first question is, how sensitive are the common fish in southeastern Wyoming to silver iodide? Secondly, how and where is silver taken up and concentrated within the fish?

Methods

Hatchery Rainbow Trout have been used in our studies thus far. These fish are common to the Medicine Bow area and are well suited for the toxicity study.

In a typical experiment, 300 to 350 four to six inch Rainbow Trout are divided among six fish tanks. It was determined that stainless steel fish tanks are best suited for the toxicity uptake studies, since silver is less readily absorbed onto the sides. Six 18-gauge stainless steel 4 ft. x 2 ft. tanks are being used. The aquaria are operated under a diluter for maintaining a series of constant concentration of silver salts in 8,640 L. of flowing water per day. The diluter, called a proportional diluter, is based on simultaneous dilution of one concentration. Mount and Brungs have described a proportional diluter in Water Research, Vol 1, pp. 21-29, 1967; and our apparatus is based on their system. Three heat exchangers are being used to cool the water to 7° C.

The purity of the water used in the aquaria is being monitored along with temperature, dissolved oxygen concentration, and pH. Organic foreign material and chlorine are removed by means of an activated carbon filtration system.

The concentration of silver in the water is adjusted so that the toxic effects of different concentrations may be studied. A teflon-lined container is being used for the toxicant-metering apparatus. It has been determined that teflon is well suited for preventing silver from plating out on the container.

One problem with silver iodide is that it is insoluble in water at low concentrations. However, by the addition of other ions to the water the silver iodide will go into solution. Both potassium iodide and sodium iodide have the ability to improve the solubility of the silver iodide and are being used in our experiments. In other experiments silver iodide is homogenized with gelatin before being added to the fish feed in a continuously-turning mixer.

Preliminary Results

The toxic action of soluble silver as silver nitrate has been studied. The trout always exhibited the same symptoms of respiratory distress in the solutions used, and their behavior just before death was similar in all cases. The 12 hour LD_{50} at 15°C was found to be 23 ppb silver nitrate. The statistical method for evaluating the dose effect by Litchfield and Wilcoxon (1948) was used to evaluate the data. Concentrations of 100, 50, 25, 12 1/2, 6 1/4 ppb of the silver salt were maintained for this experiment. The concentrations of silver in the various tanks were analyzed by the Wyoming Department of Agriculture, Division of Laboratories. No trout in the control tank died during the test. Preliminary evidence

indicates that even less silver is needed for toxic effects if the test period is extended to a few days.

Solutions of sodium nitrate were analyzed in the same manner as described above. The anion NO_3^- was found to be harmless at concentrations less than 200 ppb. A total of six trout died over a seven day period in the tank containing 200 ppb sodium nitrate. No fish died at any concentration for the first two days. These results are in agreement with the observations and conclusions of Jones (1934) who studied the toxic action of sodium nitrate on the common three-spined stickleback.

Preliminary silver nitrate experiments were repeated at a reduced temperature of 7°C with small (three inch) fish as before and with larger (10-12 inch) fish. The small fish died about ten times faster at the lower temperature than at the higher temperature. The large fish were tested only at the lower temperature and they died approximately three times slower than the small fish at the same temperature (see Table 1 below). Concentrations of 12.5 ppb and lower seems to have no significant effect on fish of either size during the ten-day experiment.

Table 1.

Size	Temperature	Percent Mortality Per Day 25 ppb Silver Nitrate
3-4"	15°	07.0%
3-4"	7°	66.6%
10-12"	7°	19.5%

The experiments with silver iodide in the feed are continuing but have not yielded any conclusive results. Concentrations of 1000 ppb to 200 ppb have been used without toxic effects.

Our attempts at obtaining aqueous solutions of silver iodide at the toxicity levels of silver nitrate have been unsuccessful. Silver iodide concentrations of 50, 25, 12.5, 6.25 and 3.12 ppb in 1 M sodium iodide were not toxic during the brief time that the silver iodide remained in solution. The same concentrations of silver iodide in 2 M sodium iodide at 16°C gave a mortality rate of 8% per day at 50 ppb. No fish died at the lower concentration, however this experiment has not been repeated, as we had difficulty with the silver iodide precipitating out of the aqueous solution.

The uptake of radioactive silver (^{110m}Ag) into various tissues of the trout was investigated. Table 2 shows the results from three Rainbow Trout, each approximately 10 inches long, exposed to ^{110m}Ag for a three-day period.

Table 2

Tissue	Counts/gram
Heart	75.03
Liver	61,600.49
Gall Bladder	669.64
Stomach	37.53
Spleen	68.50
Kidney	1,088.20
Gill	1,355.95
Blood	14.64
Brain	64.97
(Skin) Tissue	3.26
Intestine	250.87
Fat	22.24

The radioactive uptake on the whole organs or tissues was done by a gamma scintillation counting method. Results revealed that by far the highest concentration of silver was found in the liver. At least 60 times more silver accumulated in the liver as in the organs with the next highest concentration, the gills and kidney. The lowest concentration of silver was found in the skin tissue and blood.

Plans for next year

Most of our experiments need repeating in order to be confident of the results. A follow-up study will be conducted to evaluate the sub-cellular concentration of silver 110m in liver, gill, and kidney. This will help determine the toxic mode of action that silver has on trout.

Preliminary toxicity tests will be started in January 1973 on the effects of silver iodide on fish eggs. In the future, the effects of silver iodide on insects that serve as feed for fish in the Medicine Bow ecosystem will also be studied. Obviously, these toxicological experiments on fish eggs and insects will require more than one year to complete.

SUMMARY

The purpose of the Medicine Bow Ecology Project is to 1) predict probable secondary effects of a planned winter cloud seeding program, and 2) evaluate the ecological impact of cloud seeding when it actually occurs. Seven separate studies can be identified:

1. The impact of snow on herbaceous and shrubby vegetation.
2. The impact of snow on big game, especially elk.
3. The impact of spring runoff on trout and their food.
4. The impact of spring runoff on mountain lake productivity.
5. The impact of snow on litter decomposition and nutrient leaching.
6. The sensitivity of trout to various silver salts.
7. The movement of silver in ecosystems.

Only one year (one field season) has elapsed since the initiation of the Medicine Bow Project, and therefore the results presented in this Interim Report must be considered preliminary. The results of some experiments will not be available for another year or more.

Environmental data from various sites are presented, as well as data on species composition at various times during the year at the sites. The terrestrial data come from alpine tundra, subalpine meadows, and the understory of both lodgepole pine forest and spruce-fir forest. One set of data are summarized which suggest species that are either positively or negatively associated with Vaccinium scoparium, the most abundant species in the forest understory. The species that are negatively associated with V. scoparium are believed to be associated

with sites of persistant snow banks. Initial observations suggest that V. scoparium may not survive if it remains snow covered beyond late June or early July.

The movements of elk in relation to snow have been observed since January, 1972, using 50 elk with coded collars and 7 elk with radio transmitter collars. During calving season (late May and early June), the elk were all below 8800 feet and about one mile downhill from snow cover. The Report includes observations on snow cover on the winter range in 1972 and on the proximity of elk to logging operations, recreational sites, livestock, and mule deer. Mule deer were also observed during 1972, and some observations suggest that they may be more affected by snow than elk. Some streamflow and stream temperature data were obtained in 1970-72, which suggest that water temperature is cooler with increased flow rate. Trout in several streams and lakes are compared in the Report for growth rate, population size, and species composition.

A mathematical model has been constructed for the lake study and is briefly described in this Report. The field data for 1972 are summarized and will serve to validate the model, so that it can be used to help predict the effect that precipitation management might have on lake energy flow.

Silver concentration in soil, litter, and foliage is reported, and experiments are described that will help determine the rate at which silver moves through the soil profile, is carried off by runoff, or is taken up by vegetation.

The results of several Ag toxicity experiments are reported. The 12 hour LD_{50} at 15° for rainbow trout was found to be 23 ppb for silver

nitrate. Tissue analysis revealed that silver is accumulated in the liver most rapidly, with the liver having 60 times more silver than the gills or kidney. The anion NO_3^- was found to be harmless at concentrations less than 200 ppb. Concentrations of 12.5 ppb of silver nitrate seem to have no significant effect on trout. The addition of silver iodide to trout feed has had no significant effect in the experiments conducted thus far.

The Report includes a review of vegetation research that has been done in the Medicine Bow Mountains and that seems relevant to a winter precipitation management program. Considerable detail is presented on methodology and plans for the future.

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